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Complete List of Authors:	Lancova, Katerina; Institute of Chemical Technology, Prague, Department of Food Chemistry and Analysis Hajslova, Jana; Institute of Chemical Technology, Prague, Department of Food Chemistry and Analysis Poustka, Jan; Institute of Chemical Technology, Prague, Department of Food Chemistry and Analysis Krplova, Alexandra; Institute of Chemical Technology, Prague, Department of Food Chemistry and Analysis Zachariasova, Milena; Institute of Chemical Technology, Prague, Department of Food Chemistry and Analysis Dostálek, Pavel; Institute of Chemical Technology, Prague, Department of Fermentation Chemistry and Bioengineering Sachambula, Lenka; Research Institute of Brewing and Malting, Malting Institute Brno
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TRANFSER OF *FUSARIUM* MYCOTOXINS AND "MASKED" DEOXYNIVALENOL (DEOXYNIVALENOL-3-GLUCOSIDE) FROM FIELD BARLEY THROUGH MALT TO BEER

K. Lancova[1], J. Hajslova[1*], J. Poustka[1], A. Krplova[1], M. Zachariasova[1], P. Dostalek[2], L. Sachambula[3]

[*] *Corresponding author*

[1] *Institute of Chemical Technology, Prague, Department of Food Chemistry and Analysis, Technická 3, 166 28 Prague 6, Czech Republic*

[2] *Institute of Chemical Technology, Prague, Department of Fermentation Chemistry and Bioengineering, Technická 3, 166 28 Prague 6, Czech Republic*

[3] *Research Institute of Brewing and Malting, Malting Institute Brno, Mostecká 7, 61400 Brno Czech Republic*

ABSTRACT

The fate of five *Fusarium* toxins- deoxynivalenol (DON), sum of 15- and 3-acetyl-deoxynivalenol (ADONs), HT-2 toxin (HT-2) representing the main trichothecenes and zearalenone (ZON) during the malting and brewing processes was investigated. In addition to these "free" mycotoxins, the occurrence of deoxynivalenol-3-glucoside (DON-3-Glc) was for the first time, monitored in beer production chain (currently, only DON and ZON are regulated). Two batches of barley, naturally infected and artificially inoculated with *Fusarium* Spp. during the time of flowering, were used as a raw material for processing experiments. A highly sensitive procedure employing high performance liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS) was validated for analysis of "free" *Fusarium*

mycotoxins and DON-conjugate in all types of matrices. The method was able to detect also nivalenol (NIV), fusarenon-X (FUS-X) and T-2 toxin (T-2), nevertheless, none of these toxins were found in any of samples. While steeping of barley grains (the first step in malting process) apparently reduced *Fusarium* mycotoxin levels to below their quantification limits (5 - 10 µg/kg), their successive accumulation occurred during germination. In malt, the content of monitored mycotoxins was higher compared to the original barley, the most significant increase was found for DON-3-Glc. During the brewing process, significant further increases in levels occurred. Concentrations of this "masked" DON in final beers exceeded "free" DON, while in malt grists, this trichothecene was the most abundant, with the DON/DON-3-Glc ratio being approx. 5:1 in both sample series. When calculating mass balance, no significant changes were observed during brewing for ADONs, the content of DON and ZON slightly decreased, by a maximum of 30%. Only traces of HT-2 were detected in some processing intermediates (wort after trub removal and green beer).

KEYWORDS

Deoxynivalenol, deoxynivalenol-3-glucoside, conjugated mycotoxins, *Fusarium* mycotoxins, barley, malt, beer, processing.

INTRODUCTION

Beer contributes significantly to the diet of the population world-wide. The British Beer and Pub Association has reported recently (2006) that the annual per-capita consumption of this fermented drink in 2004 exceeded 100 litres in many countries, with a maximum of 157 litres in the Czech Republic. Unfortunately, barley, the major raw material used in beer production, like other cereals, can often be infected under field conditions by toxinogenic *Fusarium* species, causing the disease called *Fusarium* head blight and, consequently,

contaminated by mycotoxins. It should be noted, that hops, an ingredient supplying bittering and aroma components to beer, can be also contaminated with *Fusarium* Spp. (Solarska 2007), the disease is called in this case *Fusarium* cone tip blight (Bienapfl et al. 2001). However, until now hops have seldom been investigated as a possible source of *Fusarium* mycotoxins (Hazel and Patel 2004).

In 2003, a report on task for Scientific Cooperation (SCOOP) concerned with occurrence of *Fusarium* toxins in a wide range of food commodities, the data needed for assessment of dietary intake by the population of EU Member States become available (http://ec.europa.eu/food/fs/scoop/index_en.html). The selected information on the occurrence of these mycotoxins in barley and malt reported by participating countries (Finland, France, Italy, The Netherlands, Norway, UK) is summarised in Table I. As documented here, DON, the representative of trichothecenes *B* group, is the most abundant *Fusarium* toxin in these key raw materials used for beer production. The extent of its transfer into beer analysed in various countries worldwide is shown in Table II (Omurtag et al. 2007, Papadopoulou-Bouraoui et al. 2004, Odhav and Naicker 2002, Molto et al. 2000, Shim et al. 1997, Ruprich and Ostry 1995, Weddeling et al. 1994, Niessen and Donhauser 1993, Scott et al. 1993, Trucksess et al. 1986, Payen et al. 1983). In the two most extensive available studies focused on DON behaviour during malting and/or brewing processes (Schwarz et al. 1995, Niessen et al. 1993), fairly contradictory results, both DON increase and its decrease as compared to barley used for processing, were found, see Table III. Besides DON, the presence of ZON and 15-ADON was found in malts employed for brewing experiments, however, in the later stages, their occurrence above the method LOD, was documented only in spent grains, not in beers (Schwarz et al. 1995). It should be noted, that ZON is metabolised to α- and β-zearalenol by brewing strains of *Saccharomyces cerevisiae*. However, the occurrence of ZON and its metabolites in beer was reported only rarely, Zöllner at el. (2000) detected these

mycotoxins in only one of 23 beer samples collected in different countries, produced from different grains and under different brewing conditions. Overall, no more information on the fate of *Fusarium* toxins, others than DON, 15-ADON and ZON, during the malting and brewing processes has been available until now. Also the occurrence of conjugated forms of mycotoxins in beer has previously not been investigated, although their presence in cereals is known. The first report on "masked" mycotoxins represented typically by toxin bound to a more polar molecule like glucose, amino acids, or sulphate, appeared in the mid of the 80s when the severity of mycotoxicoses in animals was found to be greater than their determined levels in feedstuffs. It was suggested, that hydrolysis of toxin conjugates occurs in the digestive tracts releasing the levels of precursor toxins, thus increasing animals' exposure (Gareis 1994). Later on (Berthiller et al. 2005), deoxynivalenol-3-glucoside (DON-3-Glc) was reported as the major form of "masked" DON constituting up to 12% of total content of this mycotoxin in examined cereals, wheat and maize.

To avoid consumers' health risk due to unacceptably high dietary intake of *Fusarium* toxins, the European Commission has established the maximum levels for DON (1250 µg/kg in cereals; 200 µg/kg in processed cereal-based foods and baby foods) and ZON (100 µg/kg in cereals; 20 µg/kg in processed cereal-based foods and baby foods). The regulation for other fusariotoxins, the sum of HT-2 and T-2 toxin, is currently under preparation and is expected to come into the force in July 2008 (European Commission 2006). The temporary tolerable daily intakes (TDI) 1, 0.7, 0.2, and 0.06 µg/kg b.w. have been proposed for DON, NIV, ZON and the sum of T-2 and HT-2, respectively (European Commission 2006). However, it does not appear that the occurrence and significance of "masked" mycotoxins has been considered in the formulation of these limits.

The study reported here has investigated the fate of *Fusarium* mycotoxins within all steps involved in the beer production chain. The recent introduction of a pure DON-3-Glc

standard on to the market allowed the LC-MS/MS method to be established for this analyte in the matrices collected within the current malting and brewing experiments. In this way, it was possible for the first time to obtain information on the possible transfer of "masked" mycotoxins from barley infected by *fusaria* into beer.

MATERIALS AND METHODS

Chemicals

Standards of analysed mycotoxins (deoxynivalenol, DON; deoxynivalenol-3-glucoside, DON-3Glc; nivalenol, NIV; fusarenon-X, FUS-X; sum of 15- and 3-acetyl-deoxynivalenol, ADONs; T-2 toxin, T-2; HT-2 toxin, HT-2 and zearalenone, ZON) were purchased from Biopure (Austria). To ensure the accuracy of measurements certified reference material, DON naturally contaminated wheat (R-Biopharm, UK), ZON naturally contaminated milo (R-Biopharm, UK) and DON in wheat flour (BCR, Belgium), were used. The BCR reference materials were produced and certified in accordance with internationally accepted rules laid down in the various guides by BCR (Bureau Communautaire de Référence), the ISO (International Organisation for Standardisation) and the WHO (World Health Organisation).

Samples

The levels of *Fusarium* toxins in barley and malt grists that were used for processing experiments are summarized in Table IV (analytical method used for analysis is described below).

Barley for malting

For the malting experiments conducted within the first part of the presented study, two batches of barley (each 4 kg; variety Kompakt) were supplied by the Agrotest Fyto Ltd. (Kromeriz, Czech Rep.): (i) series NAT - sample containing "low levels" of mycotoxins –

naturally infected with *Fusarium* Spp., and (ii) series ART - sample with "appreciable levels of mycotoxins" inoculated in the field by spraying with a spores suspension containing a mixture of *F. culmorum* and *F. graminearum* (1:1; 10^6 conidia/ml suspension; 250-300 l/ha) at the time of barley flowering.

Malt grist for brewing

Two batches of malt grists (each 6.5 kg) were prepared by the Research Institute of Brewing and Malting (division Brno, Czech Rep.) from barleys (variety Kompakt) representing again both series, NAT and ART. It should be noted, that because of concurrence of processing experiments, mycotoxin levels in malt grists taken for brewing were not identical with those determined in products obtained in malting.

Processed products

Malted barley

Micro-malting experiments that were carried out by the Malting Institute of the Research Institute of Brewing and Malting (Brno, Czech Rep.) in line with traditional processes. Barley grains (3.5 kg) were micromalted in s small-scale malting equipment of the company KVM (CR). Malt was produced from barley within 3 key steps: i) steeping, ii) germination and iii) kilning. To initiate germination, the barley must be adequately supplied with both water and oxygen during a steeping stage and this was achieved in this study. The production of enzymes is the main purpose of the germination step. During the kilning stage, water is removed from the green malt and the malt then becomes stable and storable. Detailed descriptions of the experimental malting conditions and a list of samples taken during this process are summarised in Table V.

Beer

Beer was produced from malt grist according to a standard procedure in the brewery pilot plant at the Department of Fermentation Chemistry and Bioengineering (Institute of

Chemical Technology - ICT, Prague). In brief, the malt grist was mashed in a double mash process. After mashing, the liquid portion was separated from the spent grains by the classical lautering process. Then the wort was boiled together with added hop. After hot trub separation, fermentation was carried out with bottom-fermenting yeast. Detailed experimental brewing conditions together with a description of the samples taken throughout the beer production is summarised in Table VI.

Mycotoxin analysis

Sampling

500 g of grains were taken from thoroughly mixed barley batches delivered to the laboratory. These representative samples were ground in the laboratory mill (LM 120; Perten Instruments). For mycotoxin analysis, two sub-samples (each 12.5 g) were taken. Similar approach was employed for sampling of representative malt grists and other processing intermediates. Regarding liquid brewing intermediates and beers, 16 ml aliquots used for mycotoxin analysis were taken from100 ml samples collected within process.

Extraction and clean-up procedure for solid samples

Representative samples (12.5 g) were extracted with 50 ml acetonitrile:water mixture (84:16,v/v) for one hour using an automatic shaker (IKA Laboratortechnik, Germany). The crude extracts were then filtered (Filtrak No. 390, VEB Freiberger, Germany) and 8 ml aliquots transferred into sample tubes to which 80 µl of acetic acid (99%, Sigma-Aldrich) were added. Purification was achieved by solid phase extraction (SPE) employing MycoSep^{TM} 226 cartridges (Romer, Austria). 4 ml of purified extract were evaporated to dryness and the solid residues transferred into 1 ml of a water: methanol mixture (50:50, v/v), and passed through a 0.2 µm microfilter (Alltech, USA) prior to further analysis.

Extraction and clean-up procedure for liquid samples

The aliquots (16 ml) of processing intermediates (sweet wort, warm wort, wort after trub removal, green beer) as well as the final product (beer), were shaken after the addition of 84 ml acetonitrile and 3.2 g Celite for one hour using an automatic shaker. The extract obtained was then filtered and 5 ml aliquots were evaporated to dryness. The residues were transferred into 1 ml of a water: methanol mixture (50:50, v/v) prior to the analysis.

High performance liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS)

High performance liquid chromatography (HP1100 Binary Series LC system, Agilent Technologies, USA) coupled with mass spectrometer (Finnigan LCQ Deca, USA) were used for the analysis. Chromatographic separation of sample components was carried out on a reverse phase column with polar end-capping (Synergi Hydro RP, 150mm x 3mm x 4µm, Phenomenex, USA) held at 40 ºC and operated under gradient conditions. The mobile phase was composed of 10 mM amonium acetate in purified water (A) and methanol (B). The flow rate of the mobile phase was set to 0.5 ml/min and the injection volume was 20 µl. Gradient elution was performed starting from A:B (80:20, v/v) and reaching A:B (30:70, v/v) in 8 min. From 8 to 15 min the ratio A:B (30:70, v/v) was stable and then jumped to A:B (80:20, v:v). The time of post run lasted 7min.

Identification and quantification of analytes was performed using a tandem in time mass spectrometry (MS/MS) realised by ion trap with the following parameters (ion source type – APCI operated both in negative and positive ion modes under following conditions: capillary temperature - 150 °C, vaporizer temperature - 450 °C, nitrogen sheath gas flow – 1.2 l/min, nitrogen auxiliary gas flow – 3 l/min, source voltage - 6 kV, collision gas - helium, scan type - selected reaction monitoring). APCI positive ions in form $[M+NH_4]^+$ were used for type A trichothecenes. The ion transitions: parent > daughters (quantifier-Q, identifier- I) were as follows: HT-2: 442>273(Q),299(I) and T-2: 488>305(Q),245(I). For the type B

trichothecenes, the fragmentation of $[M+CH_3COO]^-$ in case of NIV: 371>311(Q),281(I); DON: 355>295(Q),265(I); DON-3-Glc: 517>457(Q),427(I); ADON: 397>337(Q),307(I); FUS-X: 413>353(Q),263 (I) and $[M-H]^-$ in the case of ZON: 317>273(Q),299(I) were performed.

Performance characteristics of analytical method / Quality assurance

Limits of detection (LODs) and quantification (LOQs), recoveries and repeatabilities expressed as RSDs that were obtained within the validation process are reported in Table VII. Calibration curves for all analytes were linear within the working range from 5 to 5000 µg/kg. Squared correlation coefficients (R^2) were under 0.999 for 10 point calibration curves. The analyses of all examined samples were performed in duplicate. The data shown in Tables VIII and IX are mean values corrected for analytes recoveries.

The method used for samples analysis of was accredited (ISO 17025) for cereals and, as a part of external quality control, the trueness of generated data was successfully demonstrated through participation in proficiency testing Food Analysis Performance Assessment Scheme (FAPAS) organized by Central Science Laboratory (CSL, York UK). The z-scores for analyses of HT-2 and T-2 in oat (Proficiency Test (PT) 2234), ZON in baby food (PT 2236) and maize (PT 2219), DON in wheat flour (PT 2229) and maize (PT 2224) were in the range ±2.

Moisture determination

Moisture content was determined gravimetrically by drying samples in an oven for 2 hours at 131 ± 2 ºC according to ISO Standard No. 712 “Moisture determination in cereals and cereal products”.

RESULTS AND DISCUSSION

Fusarium mycotoxins are almost unavoidable natural contaminants of barley which is the key raw material for beer production. To estimate consumers' exposure to *Fusarium* toxins from this commodity and to support identification of measures aimed at its reduction (as in the case of other contaminants), the knowledge on the fate of these hazardous fungal secondary metabolites through the production of beer is essential. The currently available information on the changes of DON and other *Fusarium* toxins during barley processing is rather contradictory and of new interest is none of the available studies was concerned with "masked" mycotoxins issue. The results obtained within this research on the behaviour of *Fusarium* toxins both during malting and brewing addresses some of these issues and should contribute to a better understanding of their fate during the beer making process.

Malting process

It is well established that, barley, depending on a crop year and agricultural practices employed, is often to some extent infected by *Fusarium* fungi, and consequently by their toxic secondary metabolites. The dynamics of *Fusarium* toxins documented by the analysis of 10 samples collected during the malting of both naturally (NAT) and artificially (ART) contaminated barleys shown in Table VIII. The relative transfer of DON, DON-3-Glc, ADONs and HT-2 (when taking their content in processed barley grains equal to 100%) are illustrated for sample series ART in Figure 1.

During the steeping stage, DON as well as ADONs levels were either eliminated (series NAT) or largely reduced to below 10% (series ART) of their original amount in the sample of barley. Similarly, a decline of DON in samples examined during this malting step, was earlier observed by Schwarz et al.(1995). Interestingly, there was a slight increase of DON-3-Glc in sample series ART occurred within steeping. While "free" mycotoxins were obviously extracted by steep water, the removal of DON conjugate, probably due to its release

from polysaccharides, was not complete. Further work is required to examine the processes involved with the DON conjugate at this and other processing stages.

During the germination stage, significant increases of mycotoxin concentrations in processing intermediates occurred in both series of experiments (NAT and ART), see Table VIII. Although DON-3-Glc, ADONs, HT-2 were below the detection limits in the NAT barley sample, these mycotoxins were detected in this germination stage. The experimental growth of *Fusarium* toxins shown in Figure 1 and Table VIII might be associated with a rapid onset of enzymatic activities in the germination of barley kernels, alternatively, *de novo* formation of fungal secondary metabolites is another conceivable cause. Worth to notice, that not only increase, but also reduction of DON in malt as compared to barley used for its production was reported in one of few older studies (Schwarz et al. 1995).

The final malting stage, kilning, did not change "free" trichothecenes levels significantly, neither thermodegradation (*Fusarium* mycotoxins are stable up to 120°C), or their additional formation as fungal growth was halted by the high temperature. The trend for DON-3-Glc was slightly different in the samples series NAT compared with ART, see Table VIII. While its levels dropped in the samples NAT, no distinct changes were observed in series ART and information on DON-3-Glc stability at higher temperatures is not clear from these data.

The final barley malt was obtained by removing the rootlets. It should be noted, that this waste product contained the highest mycotoxin levels of all intermediates taken during malting process (see Table VIII). Considering its use as a nutritive component of feeding stuffs and/or "healthy" food supplements exposure resulting from rootlets by both humans and farm animals should be taken into consideration.

Regarding the comparison of *Fusarium* toxins in the raw material (barley, series ART) and the final product (malt), the levels of DON, DON-3-Glc, ADONs and HT-2 were 2.1, 8.6,

1.1 and 2.1 times higher in malt than in barley, respectively, see Figure 1. In series NAT, DON was the only mycotoxin detected in barley, nevertheless, the malt prepared from this sample contained all the spectrum of mycotoxins (although at lower levels) as that found in ART. DON increased 3.8 times. The release from conjugated forms and/or their de novo production by growing fungi is likely to be the cause of trichothecenes levels being elevated during the malting process.

Brewing process

The ingredients needed for beer production are malt grist, hops, yeast and water. Whereas the last two items are hardly the source of mycotoxins, malt grist, as shown above, may supply significant amounts of these toxins to beer. Theoretically, hops may also contain toxic secondary metabolites produced by fungi, but no information suggesting this commodity as a source of contamination is available. In any case, hop extract is largely diluted to beer (3.4 g of hops per 1 l of beer) so their likely contribution to the overall load of *Fusarium* toxins is likely to be low. Within this part of the study, two series of malt grists prepared from NAT and ART together with respective final beers, were analysed for 7 trichothecenes and ZON; and the levels of "masked" DON, DON-3-Glc, were also determined. The results obtained are summarised in Table IX, and illustrated in Figures 2 and 3, in which the transfer of DON, DON-3-Glc, ADONs and HT-2 was calculated as a percentage according to the mass balance from the starting raw material (malt grist; 6 kg) into final beer (50 l). For better understanding of mass balance calculation based on data shown in Table VI, an example of DON-3-Glc transfer from malt grist to sweet wort follows: conjugate concentration in the NAT malt grist was 349 µg/kg giving a total amount of 2,094 µg in the 6 kg needed for preparation of 59 l sweet wort, in that DON-3-Glc level was 561 µg/kg giving a total amount

of 29,441 µg. Employing these figures for "transfer" of DON-3-Glc from the raw material to the first brewing intermediate was 29,441 / 2,094 = 14.05.

As expected, most of DON was removed from malt grist to beer, this toxin was not detected (LOQ = 5 µg/kg) in NAT spent grains (the waste from mashing step) and only 1% of the total DON was found in more contaminated ART sample. DON transfers to sweet wort were 70 and 67% in NAT and ART series, respectively. In hot wort and wort after trub removal corresponding to the ART series, DON transfer exceeded even 100%. In green beer as well as in the final beer, the total content of DON in both sample series, NAT and ART, was lower as compared to its total content in the malt grist batch taken for brewing experiments. These results are in a good agreement with an earlier study by Schwarz et al. (1995), who reported similar DON transfer rates where the values were in the range of 80-93% in four parallel brewing experiments resulting from highly contaminated malt grists (see Table III in Introduction). A distinctly opposite trend, huge increases of DON in beers, as high as 300 and 600%, were reported by Niessen and Donhauser (1993), who used two malt grists with similar DON levels (see Table III) as those in the current study. It should be noted; that a relatively accurate method (although not enabling low detection limits), gas chromatography coupled with mass spectrometry (GC/MS), was used by Schwarz et al. (1995) for target analytes quantification whereas a screening enzyme-linked immunoabsorbent assay (ELISA) based on a polyclonal antibody was employed in the Niessen's and Donhauser's study. Large discrepancies between the results of these studies can be due to possible cross-reactions associated with the ELISA method. Fairly beyond expectation, the content of this "masked" DON increased dramatically in sweet wort, hot wort and wort after trub removal prepared from both sample series, NAT and ART, as compared to its level in malt grist taken for processing. In the later case, DON transfer in these intermediates exceeded even 10^3%. The dynamics of DON-3-Glc was rather different

between the two experimental series; nevertheless, in terms of transfer to the final product, it was equal at 600% in both beers derived from NAT and ART malt grists. Interestingly, this value closely corresponded to "DON increase" reported by Niessen and Donhauser (1993), see Table III. Based on preliminary tests, for which several types of commercial ELISA kits were employed, we showed the cross-reactivity towards DON-3-Glc to be comparable to that of DON. With regard to this, until now not reported observation, it can be assumed that the data reported in Niessen's study were significantly overestimated due to the presence of DON conjugate. Its hydrolysis from bounds to higher molecular constituent is probably supported by high temperatures, 70 and 100°C, occurring in sweet wort and hot wort technological stages. To get more knowledge on "masked" mycotoxin transformation, we have initiated intensive research in this area.

In effect, ADONs, represent, another form of masked DON. As shown in Figure 2 and 3, their levels in experimental samples were almost equal or slightly higher as compared to DON. Transfer into final beers were slightly above 100%. Unfortunately, under the chromatographic conditions employed in our method (several reversed phase columns were tested), we were not able to separate 3- and 15-acetyldeoxynivalenol. It should be noted that in most of commercial DON ELISA kits, high cross-reactivity (sometimes even higher than 100%) towards 3-acetyl DON is occur is declared by producers (no declaration for DON-3-Glc). Theoretically, this trichothecene could also contribute to overestimated data shown in the study by Niessen et al. (1993).

As shown in Table VI, series ART, ZON was also transferred into beer and this estrogenic mycotoxin can be largely metabolised by *Saccharomyces cerevisiae* to *β*-zearalenol. However, this component was not monitored in our experiments. Also considering the possible occurrence of zearalenon-4-glucoside (ZON-4-Glc) in cereals (Engelhardt *et al.*, 1999), it is difficult to assess the apparent ZON transfer at 80%, since both its transformation

and/or elimination may be due to it being bound and released from conjugates during brewing process.

CONCLUSIONS

This study concerned with the fate of *Fusarium* toxins in the beer production chain starting from barley has shown many interesting results of which some have never been reported before.

Significant increases of *Fusarium* toxins (DON, ADONs and HT-2) occurred during malting process, mainly in the germination step. In addition to these trichothecenes, the presence and formation of high levels of DON-3-Glc was documented. Further significant increases in levels of this DON conjugate occurred during the brewing process. In sweet wort its relative content was ten times higher as compared to that in malt grist taken for the processing experiment. Generally, two different phenomena should be considered when explaining high levels of DON-3-Glc that can be found in beer:

(i) *De novo* growth of *Fusarium* micromycetes (either coming from spores or hyphae invading the kernels, or due to cross-contamination during this process) favoured under certain malting conditions (3 days, 14.5°C, moisture 45%) is accompanied by production of additional mycotoxins and their transformation products.

(ii) Enzymes produced during the mashing of malt grist degrade cell walls, membrane bound proteins, and starch depots in kernels, thus releasing DON-3-Glc from insoluble forms.

To get a deeper knowledge on the effect of processing on *Fusarium* toxins and their "masked" forms, more research is needed. Besides beer making other processing practices, namely those employing fermentation such as bread making, should also be investigated to

identify both additional risk sources as well as possibilities to reduce the total mycotoxin load in foods. Although the bio-availability of mycotoxin conjugates has not been fully documented yet, the possibility of approaching, or even exceeding TDI of 1 µg/kg body weight of DON established by Scientific Committee on Food (SCF) (European Commission 2006), could occur. By supposing similar toxicological profile for DON and DON-3-Glc, these conditions could occur for a 60 kg person when drinking approx. 2 glasses of "experimental" beer prepared in our study from naturally infected barley in which the sum of both "free" and conjugated DON was 77 µg/l.

There are discrepancies between the data in the literature on DON content in the beer production chain obtained by ELISA, and our results which were established by LC-MS/MS. This and other preliminary work at our laboratory lead us to assume that in part may be due to cross-reactivity of commercial test kits towards DON-3-Glc and other forms of DON. In any case, challenges in mycotoxins analysis, including the possibility to employ immunoafinity columns for simultaneous pre-concentration of both "free" and "masked" mycotoxins, have been identified.

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Table I Survey of *Fusarium* toxins in barley and malt in some EU countries; P/T = number of positive samples/total number of examined samples; mean = mean concentration (µg/kg) calculated from positive samples; max = maximum concentration (µg/kg) *(Scientific Cooperation Report, 2003)*

Country	***Food Commodity***	***DON***			***NIV***			***3-ADON***			***T-2***			***HT-2***			***ZON***		
		P/T	***Mean***	***Max***	***P/T***	***Mean***	***Max***	***P/T***	***Mean***	***Max***	***P/T***	***Mean***	***Max***	***P/T***	***Mean***	***Max***	***P/T***	***Mean***	***Max***
Finland	barley	46/77	111	619	4/77	*	351	6/77	*	101	0/77	*	*	3/77	23	41	6/77	18	53
	malt	28/68	106	394	21/68	135	293	0/68	*	*	5/68	58	153	13/68	45	47	0/50	*	*
France	barley	9/9	15	35	9/9	*	40	0/9	*	*	0/9	*	*	0/9	*	*	*	*	*
	malt	185/350	*	550	0/194	*	*	0/194	*	*	0/194	*	*	0/194	*	*	*	*	*
Italy	barley	*	*	*	*	*	*	*	*	*	1/1	280	280	*	*	*	1/1	5	5
Netherlands	barley	5/40	299	510	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Norway	barley	6/20	47	60	0/20	*	*	0/20	*	*	*	*	*	*	*	*	1/20	11	11
United Kingdom	barley	26/153	12	53	10/153	25	109	9/153	7	37	0/153	*	*	0/153	*	*	*	*	*

*this information was not available

Table II Survey of DON levels (µg/l) in beers as reported by countries worldwide; mean was calculated from positive samples

Country	*Incidence*	*Mean*	*Range*	*Reference*
Afrika	0/35	*	*	Odhav and Naicker 2002
Argentina	22/50	14.3	4 - 221	Molto et al. 2000
Canada **	29/50	5.4	0.3-50	Scott et al. 1993
Czech Republic	59/77	13	7-70	Ruprich and Ostry 1995
France	1/49	20	*	Payen et al. 1983
Germany	85/196	205	up to 569	Niessen and Donhauser 1993
Germany	18/18	5	up to 9	Weddeling et al. 1994
Korea	14/54	*	1-23	Shim et al. 1997
USA	0/14	*	*	Trucksess et al. 1986
Turkey	0/50	*	*	Omurtag et al. 2007
Austria	25/33	10.2	4.5-29.5	
Belgium	47/47	18.1	4.1-56.7	
Cyprus	5/6	8	4-12.2	
Czech Republic	17/17	21.5	4.6-55.3	
Denmark	9/9	19.9	6-47.1	
France	24/27	11	4.1-30.2	
Finland	3/4	7.4	5.2-10.6	
Germany	45/46	4.7	4-40.5	
Greece	4/4	17	16.2-16.8	
Hungary	2/2	10.8	10.5-11.1	Papadopoulou-Bouraoui et al. 2004
Ireland	2/2	8.7	7.7-9.6	
Italy	16/16	10.5	5-29.4	
Netherlands	3/4	8	5.9-9.7	
Norway	3/4	7.7	6-9.9	
Poland	10/10	17.2	5-32.9	
Sweeden	4/7	5.1	5.1-14.6	
Slovakia	9/12	13.5	5.5-36.9	
Spain	6/13	7.3	5.1-12.2	
United Kingdom	25/33	10.9	4.1-30.8	

* this information was not available
** including 17 imports

Table III Overview of literature data on changes of DON during barley processing, malting and brewing; in parenthesis DON (mg/kg) in raw material - barley)

Process	*Sample*	*% Remaining DON in processing intermediates and products*						
Malting	Barley	100 (10.6)	100 (22.5)	100 (8.5)	100 (4.8)	100 (<0.2)	*	*
	Steep-out	10	11	0	0	0	*	*
	Green Malt	36	55	18	115	0	*	*
	Kilned Malt	33	55	16	100	0	*	*
	Malt Rootlets	48	225	46	300	0	*	*
Brewing	Malt Grist	100 (3.5)	100 (17.3)	100 (1.8)	100 (6.2)	*	100 (0.44)	100 (0.034)
	Mash, 50°C	*	*	*	*	*	266	500
	Mash, 62°C	*	*	*	*	*	320	529
	Mash, 72°C	*	*	*	*	*	405	765
	First Wort	*	*	*	*	*	234	588
	Sparging	*	*	*	*	*	157	441
	Kettle full Wort	*	*	*	*	*	384	735
	Last Sparging	*	*	*	*	*	23	0
	Spent Grains	3.4	1.8	0.0	0.0	*	0	0
	Hot Wort	*	*	*	*	*	364	794
	Fermentation, day 2	*	*	*	*	*	355	*
	Fermentation, day 6	*	*	*	*	*	2625	*
	Fermentation, day 14	*	*	*	*	*	309	588
	Beer	93.4	85.0	90.0	80.0	*	323	588
Reference		Schwarz et al. 1995					Niessen and Donhauser 1993	

*this information was not available

Table IV *Fusarium* toxins* (µg/kg dry weight) in barley grains and malt grist used for processing experiments

Commodity	*Sample Code*	*Fusarium Infection*	*Sample Series Code*	*Mycotoxin*				
				DON	*DON-3-Glc*	*ADONs*	*HT-2*	*ZON*
Barley Grains	BG	natural	NAT	12	< 5	< 10	< 10	< 5
		artificial	ART	238	14	140	11	< 5
Malt Grist	MG	natural	ART	316	67	133	< 10	< 5
		artificial	NAT	1712	349	933	< 10	77

* NIV, FUS-X and T-2 were not detected in any analysed samples

Table V Characterization of pilot malting experiments

Malting Sstage	*Sample Name*	*Sample Code*	*Hours elapsed between start of processing stage and sampling*	*Experimental Conditions*
Raw material	Barley Grains	BG	-	-
1. Steeping	-	SI	24	Steeping lasted 3 days to achieve a required degree of steeping 45.5%; temperature of the steeping water and air was 14.5°C; the samples "SI, SII, SIII" were taken on three following days.
	-	SII	48	
	-	SIII	72	
2. Germination	-	GI	24	Germination stage lasted 3 days at the temperature 14.5°C; the samples "GI, GII" and the product of germination "Green Malt" were taken on three consecutive days of this stage.
	-	GII	48	
	Green malt	GM	72	
3. Kilning	-	KI	6	Kilning lasted 22 hours at kilning temperature 80°C for the period of 4 hours; the samples "KI, KII" were taken after 6 and 12 hours, respectively.
	-	KII	12	
4. Malt cleaning	Rootlets	R	-	The rootlet fraction attached to the kilned malt was removed.
	Malt	M	-	

Table VI Characterization of pilot brewing experiments

Brewing Stage	*SampleName*	*Sample Code*	*Experimental Conditions*
1. Mashing	Malt Grist (sample before mashing)	MG	Malt Grist (6 kg) was mixed with water (38°C); the total volume was 45 l; double mash process (3 hours) was used; first infusion mash at 55°C, second infusion mash at 75°C.
2. Lautering	Sweet Wort	SW	Sweet Wort (59 l) obtained by mixing of the first and the second wort (extract after sparging) was separated from Spent Grains (1.2 kg).
	Spent Grains	SG	
3. Wort boiling	Hot Wort	HW	Hops (170 g) were added to the wort during boiling (90 min); the volume of obtained Hot Wort was 50 l.
4. Wort cooling and clarifying	Wort after Trub Removal	WTR	Wort after Trub Removal was obtained after trub removal and cooling at 8°C for 1 day; the volume was approx. 50 l.
5. Fermentation	Green Beer	GB	Green Beer obtained after 10 days of fermentation at 12°C for; the volume was approx. 50 l.
6. Maturation	Beer	B	Beer after following 21 days of fermentation at 1°C ; the volume was approx. 50 l.

Table VII LC-MS/MS method validation data (n=5; sample codes are shown in Tables V and VI)

Parameter	*Matrix*	*Unit*	*Mycotoxin*

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			DON	DON-3-Glc	NIV	ADONs	HT-2	T-2	ZON	FUS-X
LOD	solid samples	µg/kg	0.5	0.5	1	1	1	0.5	1	1
	liquid samples	µg/l	1	1	5	5	5	1	1	1
LOQ	solid samples	µg/kg	5	5	10	10	10	5	5	10
	liquid samples	µg/l	5	5	10	10	10	5	5	10
Recovery */**	BG	%	88	45	64	96	91	86	75	61
	SI	%	80	38	61	101	87	101	71	63
	SII	%	87	40	66	97	90	82	69	70
	SII	%	86	34	65	92	96	83	75	62
	GI	%	79	48	62	101	98	79	71	59
	GII	%	79	38	69	106	88	89	67	62
	GM	%	89	45	61	87	90	95	72	61
	KI	%	82	46	65	92	72	99	67	69
	KII	%	78	48	64	103	92	106	69	68
	M	%	79	50	62	94	93	89	72	73
	R	%	80	38	68	90	87	82	81	64
	MG	%	84	39	71	92	97	105	79	71
	SG	%	81	44	62	87	98	84	84	68
	SW	%	105	115	102	118	105	118	109	103
	HW	%	108	121	118	117	111	124	114	104
	WTR	%	112	120	103	108	103	111	108	110
	GB	%	109	109	103	101	117	108	115	103
	B	%	117	102	102	116	110	129	104	101

* solid and liquid samples were spiked with analytes standards on levels 100 µg/kg and 50 µg/l, respectively

** uncertainty of analysis of each matrice expressed as RSD was in all cases below 10%

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Table VIII *Fusarium* toxins* (µg/kg dry weight) in samples collected during malting process (Sample codes are shown in Table V)

Sample Code	Sample Series NAT				Sample Series ART			
	DON	DON-3-Glc	ADONs	HT-2	DON	DON-3-Glc	ADONs	HT-2
BG	12	<5	<10	<10	238	14	140	11
SI	<5	<5	<10	<10	27	<5	11	<10
SII	<5	<5	<10	<10	21	8	12	<10
SIII	<5	<5	<10	<10	24	13	18	<10
GI	11	16	<10	<10	105	56	146	12
GII	21	52	19	16	204	106	148	24
GM	49	68	44	24	601	90	699	20
KI	46	17	22	37	575	82	314	47

KII	44	10	20	32	540	109	228	33
M	45	10	17	17	510	125	160	22
R	553	460	571	1061	1067	1911	641	493

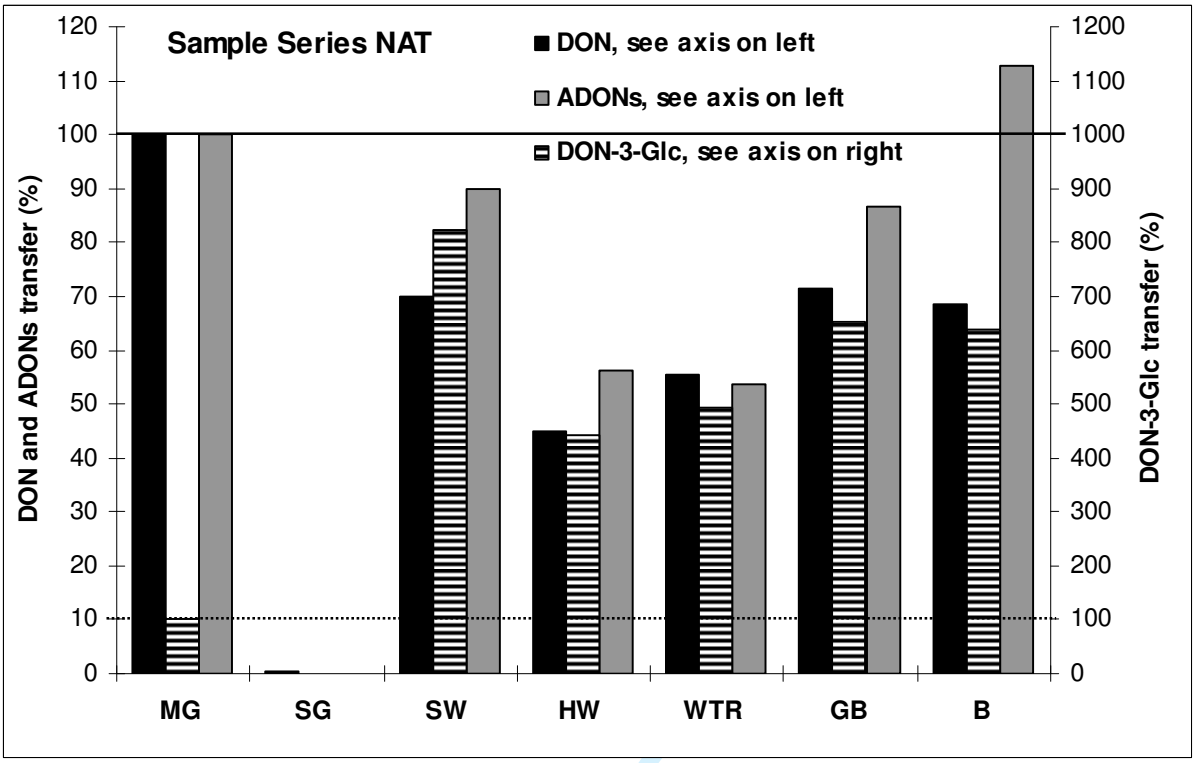
* NIV, FUS-X, T-2 and ZON were not detected in any analysed samples

Table IX *Fusarium* toxins* in samples collected during brewing process (Sample codes are shown in Table VI)

Sample Code	***Unit***	***Sample Series NAT***					***Sample Series ART***				
		DON	***DON-3-Glc***	***ADONs***	***HT-2***	***ZON***	***DON***	***DON-3-Glc***	***ADONs***	***HT-2***	***ZON***
MG	µg/kg	316	67	133	< 10	< 5	1 712	349	933	< 10	77
SG	µg/kg	6	< 5	< 10	< 10	< 5	103	838	50	< 10	59
SW	µg/l	23	56	12	< 10	< 5	116	499	65	< 10	< 5
HW	µg/l	17	35	<10	< 10	< 5	219	561	131	< 10	< 5
WTR	µg/l	21	39	< 10	< 10	< 5	237	401	104	11	< 5
GB	µg/l	27	52	14	12	< 5	180	267	115	10	< 5
B	µg/l	26	51	18	< 10	< 5	178	265	117	< 10	7

* NIV, FUS-X and T-2 were not detected in any analysed samples

Figures 2 and 3 Transfer of DON, DON-3-Glc and ADONs from malt grist to beer (total amount of mycotoxins in malt grist taken for respective beer batch production = 100%; contents of these mycotoxins in analysed samples are shown in Table IX; sample codes are specified in Table VI)



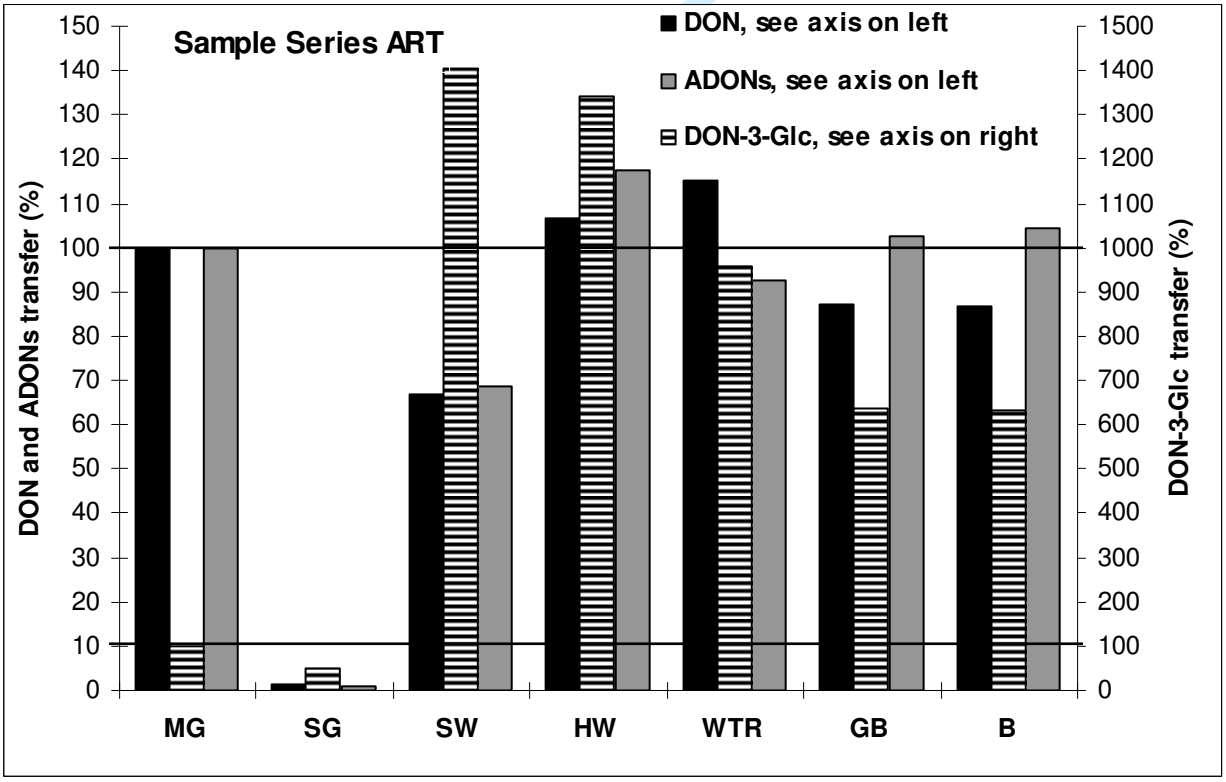


Figure 1 Transfer of DON, DON-3-Glc, ADONs and HT-2 from barley to malt, sample series ART (total amount of mycotoxins in process batch of barley grains = 100%; contents of these mycotoxins in analysed samples are shown in Table VIII; sample codes are specified in Table V)