On the Interactions Between *Fusarium* Toxin-Contaminated Wheat and Nonstarch Polysaccharide Hydrolyzing Enzymes in Diets of Broilers on Performance, Intestinal Viscosity, and Carryover of Deoxynivalenol

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ABSTRACT Wheat was inoculated with *Fusarium cul- morum*. Broiler diets were formulated to contain this *Fusarium*-infected wheat (FIW) or control wheat (CW) at a proportion of 60% and were prepared without and with an exogenous nonstarch polysaccharide (NSP) hydrolyzing enzyme preparation [endo-1,4-β-xylanase (EC 3.2.1.8) 1,000 FXU/g; ZY68, Lohmann Animal Health GmbH & Co. KG, Cuxhaven, Germany] to test the hypothesis that *Fusarium* infection-related increases in NSP hydrolyzing enzyme activities could compensate for the deleterious effects of the fungal-origin mycotoxins such as deoxynivalenol (DON). Deoxynivalenol concentration of CW and FIW amounted to 0.045 and 2.5 mg/kg of DM, respectively. After 35 d, the level of feed intake was generally lower in broilers fed the diets containing the FIW. Feed intake was stimulated by the addition of the NSP enzyme to both diet types. Similar relationships were observed for live weight gain, although the enzyme effect was much more pronounced for the CW-fed broilers, who performed even worse than the broilers fed the unsupplemented FIW. Viscosity was significantly reduced in the jejunum and the ileum by supplemental exogenous NSP hydrolyzing enzyme. However, this effect was more pronounced when the enzyme was added to the control diet, as indicated by the significant interactions between wheat and NSP enzyme. Concentrations of DON and its metabo-lite deepoxy-DON in plasma, bile, liver, and breast meat were lower than the detection limits of the applied HPLC-method. Overall, it can be concluded that feeding FIW might positively influence broiler performance and nutritional physiology, as indicated by the reduced intestinal viscosity and the less pronounced effects of addition of an exogenous NSP hydrolyzing enzyme preparation.

Key words: broiler, wheat, *Fusarium*, mycotoxin, deoxynivalenol

INTRODUCTION

A literature review on the effects of the *Fusarium* toxin deoxynivalenol (DON) in broiler diets on their performance revealed no clear relationship between dietary DON concentration and growth performance (Dänicke, 2002). Moreover, it appeared that the presence of DON in broiler diets even resulted in improved performance when compared with the respective control groups fed the uncontaminated diets. Based on this apparently relative unresponsiveness of broilers and laying hens to this mycotoxin, the critical dietary DON concentration was set 5 times higher than for the pigs at 5 mg/kg of diet (BML, 2000). The reasons for this species-related resistence were mainly discussed from a toxicological point of view and included, among others, the hypothesis of a protective effect of the renal first pass effect known to exist in chickens (Rotter et al., 1996). Feedstuffs contaminated naturally with DON and possibly other *Fusarium* toxins might adversely affect chicken health and performance. On the other hand, physiochemical alterations of the grain caused by the fungal invasion might be advantageous from a nutritional point of view. Nonstarch polysaccharides (NSP) are constituents of the plant cell wall and are shown to be altered by fungal invasion in wheat grain (Matthäus et al., 2004). Moreover, NSP hydrolyzing enzyme activities are markedly increased due to infection.

Nonstarch polysaccharides from various cereal grains are considered as antinutritive for growing chickens if they are present in diets at high concentrations. Soluble NSP increases the viscosity of the small intestinal chime, generally hampering the digestion process, whereas insoluble NSP impedes the access of endogenous enzymes to their substrates by physical entrapping (Bedford and Schulze, 1998; Dänicke et al., 1999). Therefore, it can be
hypothesized that the fungus-related alterations in cell wall could be responsible for the frequently observed improvement in broiler performance after feeding contaminated grains. To test this hypothesis, we used a 2 x 2 factorial design in which either an uncontaminated control wheat (CW) or a Fusarium-infected wheat (FIW) were fed to broilers either in the absence or presence of an exogenous NSP hydrolyzing enzyme preparation. Thus, we hypothesized that the effect of supplementation of this exogenous enzyme preparation should be less pronounced in the diet containing the infected wheat if the fungus-related cell wall cleaving enzyme activities play a significant role.

**MATERIALS AND METHODS**

**Experimental Design and Diets**

Four experimental diets were tested in total. All diets contained approximately 600 g of wheat of the Ritmo variety/kg (Table 1). The wheat was cultivated at the Mecklenhorst experimental station of the Federal Agricultural Research Center, Braunschweig, Germany, in 2003 and was either not inoculated or artificially inoculated with spores of Fusarium culmorum. The inoculation was performed with 3 isolates of *F. culmorum* at a concentration of 200,000 to 400,000 spores/mL. The inoculum suspension was sprayed onto the wheat spikes at the beginning of full blossom at a rate of 500 L/ha (50 mL/m²). Immediately before inoculation, Tween 20 was added to the suspension in a final concentration of 0.05% (0.5 mL of Tween/L of suspension) to ensure uniform dispersion of conidia.

Both the diets containing CW and the FIW were prepared with or without the addition of an NSP-hydrolyzing enzyme preparation [ZY68, Lohmann Animal Health GmbH and Co. KG, Cuxhaven, Germany; declared activity: endo-1,4-β-xylanase, EC 3.2.1.8, 1,000 FXU/g]. One FXU refers to that enzyme amount that liberates 7.8 μmol of reducing sugars (xylose equivalent) per minute at a pH of 6.0 and a temperature of 50°C from wheat azorabioxyanol. Therefore, diets differed only in the wheat source (uninfected, infected) and in the absence or presence of the NSP hydrolyzing enzyme preparation. Nutrient and energy concentrations were in the range recommended by GfE (1999). Diets were provided in a pelleted form.

**Growth Experiment**

A total of 560 1-d-old male broilers of the strain Lohmann Meat (Wiesenhof Gefflügel-Kontor GmbH, Visbeck, Germany) were used. Chicks were evenly distributed in 80 cages. Temperature and lighting regimens were in accordance with the recommendations of the breeder.

Broilers were randomly assigned to the 4 treatments, which were replicated 20 times (pens). Each replicate consisted of 7 broilers. Therefore, each treatment comprised a total of 140 chicks. The average initial live weight was similar for all groups and amounted to 44.2 ± 1.4 g. Feed and water were offered for ad libitum consumption. Broilers were vaccinated via drinking water with a live Newcastle disease virus (NDV) vaccine (LaSota, 10⁹EID₅₀) at 16 d of age. Weights of the birds and consumed feed were determined weekly until the end of the experiment at 35 d of age. After the final weighing, 20 broilers per treatment were slaughtered by cutting the neck vessels after manual stunning. Mixed trunk blood was collected from the neck vessels for determination of antibody titers and mycotoxin residue analysis. Jejunum (from the entry of the main bile and pancreatic ducts to Meckel’s diverticulum), ileum (from Meckel’s diverticulum to the ileocecal junction), pancreas, liver, spleen, bursa of Fabricius, and heart were quickly dissected after inspection of the upper digestive tract (beak, cavum oris, pharynx, esophagus). Ingesta from the jejunum and ileum were collected in precooled tubes, pooled for 6 to 7 broilers, and kept on ice before being frozen for later determination of viscosity. Bile was sampled by puncturing the gall bladder and pooled for 6 to 7 broilers. Weights of the emptied segments of the small intestine and all other dissected inner
organisms were recorded. Representative samples of breast meat and complete livers (without gall bladder) were pooled for 6 to 7 broilers and kept frozen before being further processed for mycotoxin residue analysis.

Treatments and procedures were performed according to the European Community regulations concerning the protection of experimental animals and the guidelines of the Regional Council of Braunschweig, Lower Saxony, Germany (file number 509b-42502/23-06.03).

### Analyses

Diet and wheat samples were analyzed for DM, Kjeldahl-N, and amino acids (wheat samples only) according to the methods of the Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten, as described by Naumann and Bassler (1993).

Deoxynivalenol in diet samples was analyzed by using HPLC with diode array detection after a cleanup with immunoaffinity column (IAC) according to a slightly modified protocol of the manufacturer (DONPREP, R-Biopharm Rhone Ltd., Darmstadt, Germany). The detection limit was 0.03 mg/kg, and the recovery was approximately 90% for this matrix.

Physiological samples (plasma, bile, freeze-dried liver and breast meat samples) were incubated with \(\beta\)-glucuronidase (Type H-2, Sigma, Deisenhofen, Germany) at pH 5.5 and 37°C overnight. Subsequently, plasma and bile were extracted with ethyl acetate (bile after adjusting the pH to 7) on disposable ChemElut columns (Varian Deutschland GmbH, Darmstadt, Germany) and cleaned up with IAC in the case of plasma (DONtest of VICAM, Klaus Ruttmann GmbH, Hamburg, Germany) and bile (DONPREP, R-Biopharm Rhone Ltd.). Freeze-dried liver and breast meat samples were extracted with a mixture of acetonitrile and water; defatted with petroleum ether; precleaned with a mixture of charcoal, alumina, and celite; and cleaned up with IAC (DONPREP, R-Biopharm Rhone Ltd.). Deoxynivalenol and deepoxy-DON in plasma, bile, liver, and breast meat were determined by HPLC with ultraviolet detection. The detection limit for both substances was approximately 2 and 4 ng/mL for plasma and bile, respectively, and 4 ng/g of freeze-dried liver and breast meat, with mean recoveries of 92 to 95 and 88 to 104% for DON and deepoxy-DON, respectively. Zearalenone in wheat samples was analyzed after incubation with \(\beta\)-glucosidase (EC 3.2.1.21; no. G-0395, Sigma, Taufkirchen, Germany), according to Ueberschär (1999), as described by Dänicc (2001). Further trichothecenes in wheat were analyzed by the Institute of Animal Nutrition of the University of Hohenheim, Germany, using a gas chromatogra-

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### Table 2. Wheat characteristics of uninfected control wheat (CW) and Fusarium-infected wheat (FIW)

<table>
<thead>
<tr>
<th>Item</th>
<th>CW (g/kg of DM)</th>
<th>FW (g/kg of DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP (g/kg of DM)</td>
<td>115</td>
<td>127</td>
</tr>
<tr>
<td>Amino acids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cys</td>
<td>2.6</td>
<td>2.3</td>
</tr>
<tr>
<td>Met</td>
<td>1.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Asp</td>
<td>6.0</td>
<td>5.2</td>
</tr>
<tr>
<td>Thr</td>
<td>3.3</td>
<td>2.9</td>
</tr>
<tr>
<td>Ser</td>
<td>5.2</td>
<td>4.5</td>
</tr>
<tr>
<td>Glu</td>
<td>20.7</td>
<td>18.0</td>
</tr>
<tr>
<td>Pro</td>
<td>9.7</td>
<td>8.4</td>
</tr>
<tr>
<td>Gly</td>
<td>4.7</td>
<td>4.1</td>
</tr>
<tr>
<td>Ala</td>
<td>4.1</td>
<td>3.6</td>
</tr>
<tr>
<td>Val</td>
<td>4.8</td>
<td>4.2</td>
</tr>
<tr>
<td>Ile</td>
<td>3.8</td>
<td>3.3</td>
</tr>
<tr>
<td>Leu</td>
<td>7.4</td>
<td>6.4</td>
</tr>
<tr>
<td>Tyr</td>
<td>2.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Phe</td>
<td>5.0</td>
<td>4.3</td>
</tr>
<tr>
<td>His</td>
<td>2.8</td>
<td>2.4</td>
</tr>
<tr>
<td>Lys</td>
<td>4.3</td>
<td>3.7</td>
</tr>
<tr>
<td>Arg</td>
<td>5.7</td>
<td>5.0</td>
</tr>
<tr>
<td>Mycotoxins (µg/kg of DM)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deoxynivalenol</td>
<td>45</td>
<td>2,500</td>
</tr>
<tr>
<td>Zearalenone</td>
<td>1.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Nivalenol</td>
<td>20</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Scirpentriol</td>
<td>&lt;9</td>
<td>&lt;9</td>
</tr>
<tr>
<td>T-2 tetraol</td>
<td>&lt;8</td>
<td>&lt;8</td>
</tr>
<tr>
<td>Fusarenon-X</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Monacetoxysscirpenol</td>
<td>3</td>
<td>&lt;3</td>
</tr>
<tr>
<td>15-Acetyloxyvalenol</td>
<td>8</td>
<td>&lt;8</td>
</tr>
<tr>
<td>3-Acetyloxyvalenol</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>T-2-triol</td>
<td>6</td>
<td>&lt;6</td>
</tr>
<tr>
<td>Neosolaniol</td>
<td>7</td>
<td>&lt;7</td>
</tr>
<tr>
<td>Diacetoxysscirpenol</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>HT-2 toxin</td>
<td>3</td>
<td>&lt;3</td>
</tr>
<tr>
<td>T-2 toxin</td>
<td>4</td>
<td>&lt;4</td>
</tr>
</tbody>
</table>

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phy-mass spectrometry method (Schollenberger et al., 1998). Results of mycotoxin analyses were not corrected for recovery.

Antibody titers to NDV in serum were ascertained by a hemagglutination-inhibition test (micromethod). Viscosity of jejunal and ileal ingesta was determined by using a Brookfield viscometer, as described by Dusel et al. (1998).

**Statistics**

Data were evaluated by a 2-factorial design of ANOVA:

\[ y_{ijk} = \mu + a_i + b_j + (axb)_{ij} + e_{ijk} \]

where \( y_{ijk} \) = kth observation; \( \mu \) = overall mean; \( a_i \) = effect of the wheat source (control, inoculated); \( b_j \) = effect of the addition of the NSP hydrolyzing enzyme preparation (without, with); \( (axb)_{ij} \) = interactions; \( e_{ijk} \) = error term.

All statistics were carried out using the Statistica for Windows operating system (Version 7, StatSoft, Tulsa, OK).

**RESULTS**

**Mycotoxin Pattern and Amino Acid Composition of the Uninfected and Infected Wheat**

The most obvious effect of the inoculation of the wheat with spores of *F. culmorum* was the 55 times higher DON concentration compared with the control wheat. The latter contained trace amounts of DON, zearalenone, and nivalenol (45, 1.4, and 20 μg/kg of DM, respectively), whereas nivalenol was lower than the detection limit in the *Fusarium*-infected wheat. The zearalenone concentration of 1.1 μg/kg of DM was similar to the control wheat. In addition to 2,500 μg of DON/kg of DM, the FIW contained 50 μg/kg of DM of 3-acetyl-DON. All other analyzed mycotoxins were lower than the indicated detection limits (Table 2).

The CP concentration of wheat increased by 10% due to *Fusarium* infection (Table 2). The mean average increase in amino acid concentration amounted to 12.5% and ranged between 1.6% for Met and 22.7% for Tyr. In contrast, the amino acid pattern in total wheat proteins differed much less between control and inoculated wheat. The proportions of Met, Thr, Gly, Val, and Lys of total protein decreased slightly (~1 to ~4.7%), whereas those of the remaining amino acids were still slightly higher after *Fusarium* infection (0.1 to 11.1%).

**Growth Experiment**

Feed intake was significantly reduced during the first 3 wk of the experiment due to feeding the diets containing the contaminated wheat (Table 3). In contrast, feed intake was stimulated by both diet types due to enzyme supplementation (\( P = 0.003 \)) during the last 14 d of the experiment. A significant enzyme-related stimulation of feed intake (\( P = 0.013 \)) and a generally higher level of intake in groups fed the CW was observed over the whole experimental period.

The overall mean live weight of the broilers amounted to 2.16 kg after a period of 35 d. The total mortality of 3.6% was not influenced by dietary treatments.

Live weight and live weight gain (Table 3) were significantly decreased in broilers fed the unsupplemented CW compared with all other groups when single periods or the whole experimental period of 35 d were considered. The significant interactions between both main effects were caused by the much more pronounced increase in live weight gain when the enzyme was added to the CW-containing diet as compared with the FIW-containing diet (\( P < 0.001 \)). Similar significance relationships were observed for the feed-to-gain ratio; broilers fed the nonsupplemented CW had the highest feed-to-gain ratio, whereas the other 3 experimental groups showed more or less comparable feed-to-gain ratios (Table 3).
Table 4. Organ weights (g/kg of BW) and antibody titers to Newcastle disease virus (NDV) of male broilers as influenced by uninfected control wheat (CW), *Fusarium*-infected wheat (FIW), and nonstarch polysaccharide hydrolyzing enzyme addition (n = 20)

<table>
<thead>
<tr>
<th>Wheat</th>
<th>Enzyme (g/kg)</th>
<th>Jejunum plus ileum</th>
<th>Spleen</th>
<th>Bursa of Fabricius</th>
<th>Liver</th>
<th>Heart</th>
<th>Pancreas</th>
<th>Antibody titer to NDV</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW</td>
<td>. . .</td>
<td>31.5</td>
<td>0.9</td>
<td>2.2</td>
<td>20.9</td>
<td>5.6</td>
<td>2.0</td>
<td>8.2</td>
</tr>
<tr>
<td>FIW</td>
<td>. . .</td>
<td>22.3</td>
<td>0.9</td>
<td>2.0</td>
<td>21.3</td>
<td>5.6</td>
<td>1.8</td>
<td>8.5</td>
</tr>
<tr>
<td>. . . 2</td>
<td>0.2</td>
<td>22.8</td>
<td>0.9</td>
<td>2.2</td>
<td>21.0</td>
<td>5.8</td>
<td>1.7</td>
<td>8.4</td>
</tr>
<tr>
<td>CW</td>
<td>0.0</td>
<td>39.6</td>
<td>0.8</td>
<td>2.1</td>
<td>20.6</td>
<td>5.5</td>
<td>2.4</td>
<td>7.8</td>
</tr>
<tr>
<td>CW</td>
<td>0.2</td>
<td>23.4</td>
<td>1.0</td>
<td>2.3</td>
<td>21.2</td>
<td>5.7</td>
<td>1.7</td>
<td>8.6</td>
</tr>
<tr>
<td>FIW</td>
<td>0.0</td>
<td>22.4</td>
<td>0.9</td>
<td>2.0</td>
<td>21.8</td>
<td>5.5</td>
<td>1.7</td>
<td>8.9</td>
</tr>
<tr>
<td>FIW</td>
<td>0.2</td>
<td>22.2</td>
<td>0.9</td>
<td>2.1</td>
<td>20.8</td>
<td>5.8</td>
<td>1.8</td>
<td>8.1</td>
</tr>
</tbody>
</table>

ANOVA (probabilities)

<table>
<thead>
<tr>
<th>Wheat</th>
<th>&lt;0.001</th>
<th>0.813</th>
<th>0.253</th>
<th>0.536</th>
<th>0.870</th>
<th>&lt;0.001</th>
<th>0.240</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enzyme</td>
<td>&lt;0.001</td>
<td>0.439</td>
<td>0.444</td>
<td>0.808</td>
<td>0.153</td>
<td>&lt;0.001</td>
<td>0.928</td>
</tr>
<tr>
<td>Wheat × enzyme</td>
<td>&lt;0.001</td>
<td>0.095</td>
<td>0.582</td>
<td>0.213</td>
<td>0.934</td>
<td>&lt;0.001</td>
<td>0.006</td>
</tr>
<tr>
<td>PSEM 3</td>
<td>1.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.7</td>
<td>0.2</td>
<td>0.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>

1. Titer-indicative figure, logarithm to the base 2.
2. . . indicates main effects were pooled.
3. PSEM = pooled SEM.

Organ Weights and NDV Titers

Relative weights of jejunum plus ileum and pancreas were significantly affected by wheat (P < 0.001), enzyme (P < 0.001), and by the interaction of wheat and enzyme (P < 0.001) (Table 4). The weights of the jejunum plus ileum and that of pancreas, relative to live weight, were significantly increased in broilers fed the unsupplemented CW, whereas the relative organ weights for other experimental groups were similar. The weights of other organs (bursa of Fabricius, spleen, liver, heart) were not significantly affected by dietary treatments.

Antibody titers to NDV were not consistently influenced by the main effects (Table 4). Enzyme supplementation to the CW-containing diet caused an increase in titers, whereas the opposite was detected when the enzyme was added to the diet containing FIW.

Viscosity of Intestinal Ingesta

Viscosity in both jejunal and ileal ingesta was significantly reduced by supplementing diets with NSP enzyme (Figure 1). However, this effect was more pronounced after feeding the control diet, as indicated by the significant interactions between CW and the NSP enzyme (P = 0.016 and 0.033 for jejunal and ileal ingesta, respectively, Figure 1).

Mycotoxin Residues

Concentrations of DON and of its deepoxidized metabolite deepoxy-DON were lower than the detection limits of 2 and 4 ng/mL in plasma and bile, respectively, and 4 ng/g of freeze-dried liver and breast meat corresponding to approximately 1.5 ng/g of fresh weight of the applied HPLC method.

DISCUSSION

That inoculation of the wheat with spores of *F. culmorum* resulted in a successful infection might be deduced by the 55 times higher DON concentration of the inoculated wheat compared with the uninfected control wheat. However, the absolute level of DON was approximately just one-third of that achieved by the inoculation in 2001 (Matthäus et al., 2004), although similar strains of *F. culmorum* were used as inoculum, that the similar wheat variety was inoculated, and that the wheat was cultivated at a comparable cultivation area. The lower DON yield might therefore be explained by the dry and warm weather conditions during wheat flowering in 2003. Such weather conditions might protect the wheat plant from a massive infection and mycotoxin formation (Obst et al., 2000; Oldenburg et al., 2000).

![Figure 1](https://academic.oup.com/ps/article-abstract/86/2/291/1529551/1529551)
The evaluation of the effects of cereal grains infected with Fusarium spp. requires a complex view of fungus-related alterations of the grain, which could potentially interfere with the health and performance of growing broilers (Figure 2). It needs to be stressed that these alterations not only include the toxin formation but also complex alterations of the grain matrix. Therefore, the sole consideration of Fusarium toxins or of a prominent toxin such as DON in interpreting the effects of feeding contaminated grains to broilers seems to be insufficient. This was clearly demonstrated by the results of the present experiment. The supplementation of a diet containing CW with an NSP-hydrolyzing enzyme preparation, and a comparison of the effects on broilers with those obtained when the enzyme was added to a diet containing FIW, was shown to be a useful tool to differentiate between the effects of FIW on one hand and NSP hydrolyzing enzyme activities originating from the fungus invasion on the other.

Detailed investigations of wheat grains infected artificially with spores of F. culmorum by inoculation have revealed that CP, amino acid, and crude ash concentrations were significantly increased, whereas starch concentration decreased at the same time (Matthäus et al., 2004). These relationships for CP and amino acids could be confirmed by the results of the present experiment and might be explained by increased proportions of the aleurone layer or grain husk to starch endosperm and, consequently, per unit of grain weight, as indicated by a decreased thousand-seed weight of infected grains (Miedaner et al., 2000; Schwarz et al., 2001; Matthäus et al., 2004). Although the relative changes due to inoculation are more pronounced when the alterations in amino acid concentration are related to DM rather than to protein, the shift in the proportion of particular amino acids in the protein fraction should not be overlooked. Such obvious shifts were consistently observed in the experiment by Matthäus et al. (2004) and in the present study for Phe and Tyr and amounted to 7 and 9% and to 7 and 11%, respectively. They could indicate a shift in individual grain proteins differing in amino acid composition. Thus, the discussed alterations in the proportions between husk and endosperm might not only evoke quantitative but also qualitative alterations of grain proteins, which, in turn, might also have consequences on digestibility of these proteins. In addition, it could also be possible that fungus protein itself contributed to the discussed amino acid shifts. In any case, the net effect of the Fusarium infection resulted in an increased amino acid supply for the broilers fed the diets containing this wheat and might consequently have contributed to the observed effects on performance.

The alterations in the husk-to-endosperm ratio might also include an increase in the concentration of cell wall constituents, with a concomitant increase in the proportion of soluble NSP (Matthäus et al., 2004). These were particularly shown to be positively related to the water extract viscosity of wheat (Dusel et al., 1997) and to viscosity of the liquid phase of the small intestine of broilers (Bedford and Classen, 1992).

However, these relationships might not fully apply for Fusarium-infected grains, as indicated by the inverse relationship between the infection-related increase in the concentration of soluble NSP, with a related enhancement in cell wall cleaving enzyme activities, and the concomitant decrease in water extract viscosity of that wheat (Matthäus et al., 2004). The overall extract viscosity needs to be viewed as a parameter influenced by several factors, of which soluble NSP is only 1 determinant. The net extract viscosity might therefore result from other infection-related changes in the grain. Marked alterations in the macronutrients starch and protein might be deduced from the Fusarium infection-caused increases in amylase and protease activities (Schwarz et al., 2001, Matthäus et al., 2004). Whatever the reasons for an altered extract viscosity, it could be closely related to viscosity of the small intestinal supernatant, with a generally higher level in ileum than in jejunum, and to the performance of broilers (Bedford and Classen, 1993). It was clearly demonstrated by the present results that the net effect of the Fusarium infection caused a decreased intestinal viscosity after feeding the diet containing nonsupplemented FIW when compared with the group fed the diet containing nonsupplemented CW. Moreover, the plumage of all broilers of the latter group appeared to be fouled with excreta, whereas that of the broilers of the other 3 groups was markedly cleaner. The dirty plumage has been linked to an increased water consumption caused by the increased intestinal viscosity (Jeroch et al., 1995) and can be considered as a hygienic risk for the affected broilers. Dirty plumage may be a visible effect of the repeatedly demonstrated depression in nutrient digestibility evoked by an increased intestinal viscosity (Bedford and Schulze, 1998; Dänicke et al., 1999). Moreover, the significantly increased weights of the emptied small intestine and of the pancreas, relative to live weight, of the broilers fed the diet containing nonsupplemented CW paralleled the increased intestinal viscosity. Intestinal viscosity-related

Figure 2. The dual character of a Fusarium infection of cereal grains for broilers.
increases in these organ weights were found to be related to an increased fractional protein synthesis of these tissues (Dänicke et al., 2000a) and enhanced endogenous N losses (Dänicke et al., 2000b). These energy- and nutrient-intensive metabolic alterations might have also contributed to the lower live weights of the broilers fed the nonsupplemented CW-containing diet of the present experiment.

The effects of DON were obviously much less pronounced or could even have been compensated by the discussed Fusarium infection-related grain alterations. It must be stressed that the dietary DON concentrations were rather low and approximately just one-third of the critical concentration of 5 mg/kg of diet (BML, 2000). However, from a practical point of view, such concentrations, which can be considered to be critical for pigs, might be much more realistic than the indicated 5 mg of DON/kg of broiler diet. The antibody titers to NDV were frequently shown to be indicative for a DON intoxication of poultry and were shown to be decreased in rearing chickens, laying hens, and broilers after the feeding of diets with rather high DON concentrations from 12 to 18 mg/kg of diet (Harvey et al., 1991; Dänicke et al., 2002, 2003). In the present experiment, in which dietary DON concentrations were 1.4 and 1.5 mg/kg in the diets containing the FIW, the antibody titers were inconsistently influenced when compared with the groups fed the CW. Thus, the dietary DON concentrations were too low to significantly influence the broiler's response to the NDV vaccine. Moreover, neither DON nor deoxy-DON were detected in any of the analyzed specimens (blood, breast muscle, liver, and bile). This indicates an effective elimination of the toxin from the broiler’s body, which is in contrast to pigs in which DON residues can be measured in blood and bile, even when the diets contained <1 mg of DON/kg of diet (Döll et al., 2003; Dänicke et al., 2004b, 2005).

The results of the present experiment clearly indicate the necessity to consider not only the DON contamination of wheat in evaluating its effect on broiler health and performance but also the implicated physicochemical alterations due to the infection or invasion of the fungus. Thus, the net effect of feeding such wheat to broilers depends on the balance between the toxic effects of DON and other Fusarium toxins and the positive nutritional effect of the Fusarium infection (Figure 2) from which the lowering of the intestinal viscosity seems to be of major importance. The latter could also be confirmed for turkeys (Dänicke et al., 2006) and ducks (Dänicke et al., 2004a).

ACKNOWLEDGMENTS

The inoculation experiment was kindly performed by the co-workers of the Mariensee and Mecklenhorst experimental stations. The assistance of the co-workers of the Institute for Animal Welfare and Animal Husbandry and of the Institute of Animal Nutrition in performing the experiment and analyses is gratefully acknowledged. We thank Margit Schollenberger, Institute of Animal Nutrition, University of Hohenheim, for performing the analyses of the trichothecenes.

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