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Effects of Feeding Barley Naturally Contaminated with Fusarium Mycotoxins on Growth Performance, Nutrient Digestibility, and Blood Chemistry of Gilts and Growth Recoveries by Feeding a Non-contaminated Diet

C. Kong, S. Y. Shin, C. S. Park, and B. G. Kim*
Department of Animal Science and Technology, Konkuk University, Seoul 143-701, Korea

ABSTRACT: The objectives of this study were to investigate the effects of feeding barley naturally contaminated with *Fusarium* mycotoxins on growth performance, vulva swelling, and digestibility of dry matter, organic matter, and crude protein of gilts and the recovery of gilts fed normal diets immediately after the exposure to contaminated diets by measuring growth performance and vulva swelling. In Exp. 1, four diets were prepared to contain 0%, 15%, 30%, or 45% contaminated barley containing 25.7 mg/kg deoxynivalenol and 26.0 μg/kg zearalenone. Sixteen gilts with an initial body weight (BW) of 33.3 kg (standard deviation = 3.0) were individually housed in a metabolism crate and assigned to 4 diets with 4 replicates in a randomized complete block design based on BW. During the 14-d feeding trial, individual BW and feed consumption were measured weekly and the vertical and horizontal lengths of vulva were measured every 3 d. From d 10, feces were collected by the maker-to-marker method for 4 d. Blood samples were collected on d 14. During the overall period, the average daily gain, average daily feed intake, and gain:feed of pigs linearly decreased ($p<0.01$) as the dietary concentration of contaminated barley increased. However, the digestibility of crude protein was linearly increased ($p = 0.011$) with the increasing amounts of contaminated barley. Increasing dietary *Fusarium* mycotoxin concentrations did not influence vulva size, blood characteristic as well as immunoglobulin level of pigs. In the Exp. 2, a corn-soybean meal-based diet was formulated as a recovery diet. Pigs were fed the recovery diet immediately after completion of the Exp. 1. During the 14-d of recovery period, the individual BW and feed consumption were measured weekly and the vertical and horizontal length of vulva were measured every 3 d from d 0. On d 7, the feed intake of pigs previously fed contaminated diets already reached that of pigs fed a diet with 0% contaminated barley and no significant difference in growth performance among treatments was observed during d 7 to 14 of the recovery period. In conclusion, increasing levels of mycotoxins in diets linearly decreased the growth performance of pigs, and these damages can be recovered in 7 d after the diet was replaced with a normal diet. The vulva size, blood characteristic, immune responses were not affected by increasing level of contaminated barley in the diets fed to pigs. (**Key Words:** Deoxynivalenol, Growth, Mycotoxin, Swine, Zearalenone)

INTRODUCTION

There is growing concern for mycotoxins on swine production as they can cause reduced growth and feed intake, organ damage, and altered immune responses of pigs (Chaytor et al., 2011). Among various mycotoxins, *Fusarium* mycotoxins are secondary toxic metabolites produced by various species of the genus *Fusarium* such as *F. graminearum* and *F. culmorum* and frequently found in various feedstuffs for swine diet thus have received considerable attention (CAST, 2003; Chaytor et al., 2011). Deoxynivalenol (DON) and zearalenone (ZON) are the most important *Fusarium* mycotoxins in terms of frequency of occurrence as well as concentration of toxins relative to guidance level (CEC, 2006; Rodrigues and Naehrer, 2012a).

Because pigs are known to be very susceptible to DON (Prelusky et al., 1994), several studies were conducted to find feed additives ameliorating the detrimental effects of

* Corresponding Author: B. G. Kim. Tel: +82-2-2049-6255, Fax: +82-446-6255, E-mail: bgkim@konkuk.ac.kr
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DON but their effects are still equivocal (Papaioannou et al., 2002; Weaver et al., 2013; Xiao et al., 2013; Kong et al., 2014). The most apparent signs of DON intoxication are reduced feed intake and consequent body weight (BW) loss of pigs. The DON also modulates immune responses as well as affects blood chemistry in pigs (Bergsjo et al., 1993; Swamy et al., 2002; Dänicke et al., 2004b). The ZON known as a mycoestrogen and estrogenic properties of its metabolites have been reported to cause reproductive disorders by hyperestrogenism (Takemura et al., 2007; Kanora and Maes, 2009; Jiang et al., 2010).

Barley ranks in fifth in global grain production (USDA, 2014). Although energy content in barley is about 10% to 15% less than that in corn, barley is still a very attractive ingredient for swine diet because of higher contents of crude protein (CP), lysine, and digestible phosphorus compared with corn (NRC, 2012; Woyengo et al., 2014). In addition, feeding diets containing barley up to 60% at the expense of corn did not show any detrimental effects on animal performances (Kim et al., 2014). A global survey for the incidence of mycotoxins in various feedstuffs indicated that the positive occurrences of DON and ZON in barley were 42% and 38%, respectively, and the average concentrations of DON and ZON were 1.677 and 0.323 mg/kg which are greater than the suggested guidance levels of mycotoxins for swine diets at 0.9 and 0.1 mg/kg, respectively (CEC, 2006; Rodrigues and Naehrer, 2012b). Moreover, it was reported that the effect of *Fusarium* mycotoxins on growth performance of pigs was dependent on the source of mycotoxin (i.e. purified vs naturally contaminated) in ingredient (Prelusky et al., 1994). However, little data from study feeding contaminated barley with *Fusarium* mycotoxins to pigs is available. Therefore, the objectives of the present study were to investigate the effects of feeding barley naturally contaminated with *Fusarium* mycotoxins on growth performance, vulva swelling, and digestibility of dry matter (DM), organic matter (OM), and CP for gilts and the recovery of gilts fed normal diets immediately after the exposure to the contaminated diets by measuring growth performance and vulva size.

MATERIALS AND METHODS

All the experimental procedures used in the current study were approved by the Institutional Animal Care and Use Committee at Konkuk University.

Exp. 1

Animals and experimental design: In a 14-d experiment, 16 crossbred gilts with an average initial BW of 33.3 kg (standard deviation = 3.0) were individually housed in metabolism crates (0.48×1.49 m) in an environmentally controlled room. The pigs were allotted to 4 dietary treatments in a randomized complete block design with 4 blocks based on BW.

Ingredients, diets, feeding, and sample collection: The concentration of DON in the corn, soybean meal (SBM), control barley, or naturally contaminated barley used were analyzed to be 0.6, 1.0, 0.3, or 25.7 mg/kg, respectively, and the concentrations of ZON were less than the detection limit (25.0 μg/kg) except for contaminated barley which was analyzed to be 26.0 μg/kg (Table 1).

A corn-SBM based diet containing 45% of control barley was prepared and 3 additional diets were also formulated to contain 15%, 30%, or 45% of the contaminated barley at the expense of the control barley (Table 2). Individual BW and feed consumption were measured on d 0, 7, and 14 and at the completion of experiment on d 14 average daily gain (ADG), average daily feed intake (ADFI), and gain:feed (G:F) were calculated. Individual vertical and horizontal lengths of vulva were measured on d 0, 3, 6, 9, and 12. From d 10 to 14, fecal samples were collected quantitatively by the marker-to-marker method as described by Kong and Adeola (2014). Blood samples were collected from all the pigs at the completion of study on d 14.

Mycotoxins and chemical analyses: The concentration of DON and ZON in the ingredients and diets were determined by using enzyme-linked immunosorbent assay kits (AgraQuant, Romer Labs Inc., Singapore, Republic of Singapore) which had quantification ranges for analysis on DON and ZON from 250 to 5,000 and 25 to 1,000 ng/mL, respectively.

All the fecal samples and orts collected for each gilt were dried in a forced-air oven at 55℃ to constant weight and ground using a coffee grinder. Dry matter analysis of samples was performed by drying the samples in a forced-air oven at 135℃ for 2 h (method 930.15; AOAC, 2005). Nitrogen content of samples was determined by the Kjeldahl method (method 984.13; AOAC, 2005) using a Buchi K-424 digestion and B-324 distillation apparatus (Buchi, Flawil, Switzerland) and gross energy was determined by adiabatic bomb calorimeter (Parr 1261 bomb calorimeter; Parr Instruments Co., Moline, IL, USA) using benzoic acid as a calibration standard. Serum concentration

Table 1. Mycotoxin concentrations of ground corn, soybean meal, and barley as a control and a naturally contaminated one with *Fusarium* mycotoxins (as-fed basis), Exp. 1

Mycotoxin	Ground corn	Soybean meal	Barley	
			Control	Contaminated
Deoxynivalenol (mg/kg)	0.6	1.0	0.3	25.7
Zearalenone (μg/kg)	ND	ND	ND	26.0

ND, not detected.

Table 2. Ingredient and nutrient composition (%) of experimental diets containing increasing levels of barley contaminated with *Fusarium* mycotoxins (as-fed basis), Exp. 1

Item	Diet[1]			
	Contaminated barley (%)			
	0	15	30	45
Ingredient				
Ground corn	21.8	21.8	21.8	21.8
Soybean meal (48% CP)	30.6	30.6	30.6	30.6
Control barley	45.0	30.0	15.0	-
Contaminated barley	-	15.0	30.0	45.0
Limestone	0.95	0.95	0.95	0.95
Dicalcium phosphate	0.75	0.75	0.75	0.75
Salt	0.40	0.40	0.40	0.40
Vitamin-mineral premix[2]	0.50	0.50	0.50	0.50
Analyzed nutrient and energy				
Dry matter	89.3	89.1	89.5	89.4
Organic matter	84.2	83.5	83.0	83.3
CP	21.6	22.1	22.8	23.8
Metabolizable energy[3] (kcal/kg)	3,131	3,131	3,131	3,131
Analyzed mycotoxin				
Deoxynivalenol (mg/kg)	0.6	6.1	7.7	14.6
Zearalenone (μg/kg)	ND	35.4	47.8	33.7

CP, crude protein; ND, not detected.
[1] Each diet contains 0%, 15%, 30%, or 45% contaminated barley at the expense of control barley, respectively.
[2] Provided the following quantities per kg of complete diet: vitamin A, 25,000 IU; vitamin D_3, 4,000 IU; vitamin E, 50 IU; vitamin K, 5.0 mg; thiamin, 4.9 mg; riboflavin, 10.0 mg; pyridoxine, 4.9 mg; vitamin B_{12}, 0.06 mg; pantothenic acid, 37.5 mg; folic acid, 1.10 mg; niacin, 62 mg; biotin, 0.06 mg; Cu, 25 mg as copper sulfate; Fe, 268 mg as iron sulfate; I, 5.0 mg as potassium iodate; Mn, 125 mg as manganese sulfate; Se, 0.38 mg as sodium selenite; Zn, 313 mg as zinc oxide; butylatedhydroxytoluene, 50 mg.
[3] Calculated value based on NRC (2012).

of immunoglobulin subsets (IgA, IgG, and IgM) was determined on a Cobas Integra 800 analyzer (Roche, Mannheim, Germany). An automated blood chemistry analyzer (Roche Cobas c702; Roche, Germany) was used to measure the amounts of albumin, globulin, alkaline phosphatase (ALP), Ala transaminase (ALT), Asp transaminase (AST), γ-glutamyl transferase (GGT), blood urea nitrogen (BUN), calcium, glucose, phosphorus, and total protein in the serum samples.

Exp. 2

Diets and feeding: A 14-d feeding trial was conducted to evaluate the recovery of pigs that previously consumed diets contaminated with mycotoxin in Exp. 1. Immediately after ending of Exp. 1, the pigs were fed a corn-SBM-based standard diet (Table 3) which met or exceed the nutrient requirement estimates of pigs (NRC, 1998). Individual pig BW and feed consumption were measured on d 0, 7, and 14 and the vertical and horizontal lengths of vulva were measured every 3 days from d 0 to 14.

Table 3. Ingredient and nutrient composition (%) of recovery diet (as-fed basis), Exp. 2

Item	Diet
Ingredient	
Ground corn	67.2
Soybean meal (48% CP)	28.0
Soybean oil	2.00
L-Lys·HCl (78.8%)	0.20
Limestone	0.90
Dicalcium phosphate	1.00
Salt	0.40
Vitamin premix[1]	0.10
Mineral premix[2]	0.20
Analyzed nutrient and energy	
Dry matter	84.5
CP	19.1
Metabolizable energy[3] (kcal/kg)	3,384

CP, crude protein.
[1] Provided the following quantities per kg of diet: vitamin A, 20,000 IU; vitamin D_3, 4,200 IU; vitamin E, 100 IU; vitamin K_3, 5.6 mg; thiamin, 2.8 mg; riboflavin, 5.5 mg; pantothenic acid, 14 mg; pyridoxin, 4.2 mg; biotin, 0.1 mg; cyanocobalamin, 0.042 mg; niacin, 42 mg; folacin, 1.1 mg; ethoxyquin, 1.1 mg.
[2] Provided the following quantities as milligram per kg of diet: Fe, 100 mg as iron sulfate; Cu, 70 mg as copper sulfate; Zn, 48 mg as zinc sulfate; Mn, 60 mg as manganese sulfate; Co, 0.4 mg as cobalt sulfate; I, 0.8 mg as calcium iodate; Se, 0.5 mg as sodium selenite.
[3] Calculated value based on NRC (2012).

Calculations and statistical analyses

For each of the experimental diets, the apparent total tract digestibility of DM, OM, and CP was determined according to the total collection method as described by Kong and Adeola (2014).

The experimental data were statistically analyzed using MIXED procedures of SAS (SAS Inst. Inc., Cary, NC, USA). The independent variables in the model included diet as a fixed effect and block as a random effect. Growth performance including ADG, ADFI, and G:F, immune responses and blood characteristics were response variables and each animal was considered as an experimental unit. Orthogonal polynomial contrasts were used to show linear or quadratic responses to the level of contaminated barley in the experimental diets and specific orthogonal contrasts were also used to compare the recovery results between pigs previously fed diet without and with contaminated barley. The alpha level used for the determination of statistical differences was set at 0.05. Probability values between 0.05 and 0.10 were considered tendencies.

RESULTS

Exp. 1

Mycotoxin analysis: The concentrations of DON and

ZON in diets containing 0%, 15%, 30%, or 45% contaminated barley were analyzed to be 0.6, 6.1, 7.7, or 14.6 mg/kg and 23.8, 35.4, 47.8, or 33.7 μg/kg, respectively (Table 2).

Growth performance and vulva size: From d 0 to 7, the ADFI for pigs fed increasing level of the contaminated barley in the diets showed linearly decreasing trend (p = 0.056) and the ADG and G:F decreased linearly (p = 0.011) as the contaminated barley levels increased (Table 4). From d 7 to 14, the ADG and ADFI of pigs linearly decreased (p<0.01) with increasing level of the contaminated barley in the diets whereas the G:F of pigs showed linearly decreasing trend (p = 0.063). On d 14, the final BW of pigs fed diets with increasing level of the contaminated barley linearly decreased (p = 0.017). During the overall period, all growth performance measurements linearly decreased (p<0.01) as the level of contaminated barley in the diets fed to pigs increased.

The vulva size of pigs fed the diets with increasing level of contaminated barley was not affected throughout the 12-d period (Table 5).

Digestibility: The daily feed DM, OM, and CP intake as well as the respective feces components output linearly decreased (p<0.01) as the level of the contaminated barley in the diets increased (Table 6). However, the CP digestibility linearly increased (p = 0.011), and the digestibility of DM (p = 0.065) and OM (p = 0.060) showed increasing trend as the contaminated barley in the diets increased.

Serum immunoglobulin and blood characteristics: The concentrations of serum IgA, IgG, and IgM were not influenced by the increase of the contaminated barley in diets fed to pigs (Table 7). Feeding of increasing level of the contaminated barley to pigs linearly increased BUN (p = 0.016) whereas other blood chemistry measurements were not affected.

Exp. 2

Growth performance: From d 0 to 7, the ADG and G:F of pigs previously fed 15% or 45% of the contaminated barley in diets was greater (p<0.05) compared with pigs previously fed the control barley in diet (Table 8). No difference was observed in the growth performance among the pigs previously fed the diets containing 0%, 15%, 30%, or 45% of contaminated barley from d 7 to 14. For the overall period, the ADG of pigs previously fed 15% or 45% of the contaminated barley in diets was greater (p<0.05) compared with the pigs previously fed the control barley diet.

Vulva size: During the recovery period, the vulva size measured was not influenced by the levels of the contaminated barley in diets fed previously (Table 9).

DISCUSSION

Exp. 1

The difference between the analyzed and calculated concentrations of mycotoxins in the experimental diets based on the analyzed values of the individual ingredient was observed in the present study. This is in agreement with

Table 4. Growth performance of pigs fed experimental diets containing increasing amounts of barley naturally contaminated with *Fusarium* mycotoxins[1], Exp. 1

Item	Diet[2]				SEM	p-value	
	Contaminated barley (%)						
	0	15	30	45		Linear	Quadratic
d 0 to 7							
Initial BW (kg)	32.5	33.0	33.0	34.8	1.0	0.143	0.497
ADG (g/d)	589	614	475	57	122	0.011	0.104
ADFI (g/d)	1,332	1,297	1,155	848	163	0.056	0.425
G:F	0.42	0.47	0.38	0.06	0.08	0.011	0.044
Final BW (kg)	36.7	37.3	36.3	35.2	1.3	0.385	0.517
d 7 to 14							
ADG (g/d)	575	511	211	171	81	0.002	0.881
ADFI (g/d)	1,768	1,658	1,281	1,071	86	<0.001	0.572
G:F	0.32	0.31	0.13	0.16	0.07	0.063	0.724
Final BW (kg)	40.7	40.9	37.8	36.4	1.2	0.017	0.531
d 0 to 14							
ADG (g/d)	582	563	343	114	69	<0.001	0.163
ADFI (g/d)	1,550	1,478	1,218	959	114	0.003	0.435
G:F	0.37	0.38	0.26	0.11	0.04	<0.001	0.087

SEM, standard error of the mean; BW, body weight; ADG, average daily gain; ADFI, average daily feed intake; G:F, gain:feed.
[1] Each least squares mean represents 4 observations.
[2] Each diet contains 0%, 15%, 30%, or 45% contaminated barley at the expense of control barley, respectively.

Table 5. Vulva size of pigs fed experimental diets containing increasing amounts of barley naturally contaminated with *Fusarium* mycotoxins[1], Exp. 1

Item	Diet[2]				SEM	p-value	
	Contaminated barley (%)						
	0	15	30	45		Linear	Quadratic
d 0							
Width (mm)	19.7	17.3	19.0	16.5	2.3	0.432	0.990
Length (mm)	24.7	22.0	19.0	21.5	1.8	0.121	0.135
Area[3] (mm^2)	245	193	182	179	36	0.198	0.466
d 3							
Width (mm)	20.0	16.3	19.8	17.5	1.9	0.653	0.706
Length (mm)	27.0	26.3	23.3	26.8	1.5	0.601	0.203
Area (mm^2)	284	215	233	235	36	0.439	0.350
d 6							
Width (mm)	20.0	17.3	20.0	17.5	1.9	0.589	0.949
Length (mm)	27.8	28.5	26.8	27.0	1.4	0.531	0.860
Area (mm^2)	287	247	269	236	35	0.421	0.922
d 9							
Width (mm)	21.5	18.3	20.8	18.0	2.0	0.397	0.904
Length (mm)	31.0	27.5	25.8	27.5	1.9	0.176	0.193
Area (mm^2)	344	251	269	248	43	0.191	0.425
d 12							
Width (mm)	20.5	16.5	19.3	18.0	1.7	0.551	0.443
Length (mm)	30.3	27.8	26.5	27.8	1.5	0.229	0.247
Area (mm^2)	319	228	260	250	37	0.314	0.308

SEM, standard error of the mean.
[1] Each least squares mean represents 4 observations except the diet containing 0% contaminated barley in d 0 (3 observations).
[2] Each diet contains 0, 15, 30, and 45% contaminated barley at the expense of control barley, respectively.
[3] Area (mm^2) = [Width (mm)×Length (mm)]/2.

Swamy et al. (2003) who also observed much higher analyzed values of DON compared with the intended values in diets. This might be attributed to uneven distribution of mycotoxins in the ingredients used. The analyzed mycotoxin also showed that the contaminated barley used in the present study was primarily contaminated with DON rather than ZON.

Increasing level of contaminated barley with *Fusarium* mycotoxins negatively affected growth performance of growing pigs. Feed intake depression and consequent decrease of BW gain were commonly observed and are considered as the major adverse effects of feeding DON-contaminated diets to pigs (Swamy et al., 2003; Goyarts et al., 2005; Mok et al., 2013) and these effects were also

Table 6. Dry matter (DM), organic matter (OM), and crude protein (CP) digestibility of pigs fed experimental diets containing increasing amounts of barley naturally contaminated with *Fusarium* mycotoxins[1], Exp. 1

Item	Diet[2]				SEM	p-value	
	Contaminated barley (%)						
	0	15	30	45		Linear	Quadratic
DM intake (kg/d)	1.66	1.57	1.17	1.03	0.09	0.001	0.820
OM intake (kg/d)	1.57	1.47	1.08	0.96	0.08	< 0.001	0.882
CP intake (g/d)	404	388	297	274	22	0.002	0.881
Fecal DM output (g/d)	322	294	205	168	29	0.004	0.890
Fecal OM output (g/d)	281	255	174	142	26	0.004	0.908
Fecal CP output (g/d)	82.1	72.5	49.9	34.4	9.1	0.005	0.757
DM digestibility (%)	80.4	81.3	83.0	83.8	1.2	0.065	0.954
OM digestibility (%)	81.8	82.7	84.5	85.3	1.2	0.060	0.969
CP digestibility (%)	79.3	81.4	84.4	87.6	1.8	0.011	0.756

SEM, standard error of the mean.
[1] Each least squares mean represents 4 observations except the diet containing 0% contaminated barley (3 observations).
[2] Each diet contains 0%, 15%, 30%, or 45% contaminated barley at the expense of control barley, respectively.

Table 7. Immunoglobulin and biological blood assay of pigs fed experimental diets containing increasing amounts of barley naturally contaminated with *Fusarium* mycotoxins[1,2], Exp. 1

Item	Diet[3]				SEM	p-value	
	Contaminated barley (%)						
	0	15	30	45		Linear	Quadratic
Immunoglobulin (mg/dL)							
IgA	46.0	46.5	44.8	43.3	2.6	0.412	0.709
IgG	661	662	662	745	46	0.254	0.399
IgM	46.3	72.5	60.3	85.3	11.6	0.075	0.958
Biological blood assay[5]							
Albumin (g/dL)	3.98	4.00	3.43	3.68	0.22	0.161	0.615
Globulin (g/dL)	2.50	2.68	3.33	3.20	0.29	0.062	0.616
Albumin:globulin	1.82	1.50	1.10	1.17	0.28	0.090	0.493
Total protein (g/dL)	6.48	6.68	6.75	6.88	0.26	0.296	0.887
ALP (U/L)	206	117	102	99	40	0.094	0.304
ALT (U/L)	38.3	44.3	43.5	52.0	4.3	0.064	0.777
AST (U/L)	90.0	67.8	39.5	79.3	31.9	0.682	0.357
GGT, U/L	65.8	55.8	54.5	43.5	11.8	0.231	0.967
BUN (mg/dL)	15.9	19.3	17.4	21.6	1.2	0.016	0.737
Calcium (mg/dL)	10.7	11.2	10.4	10.6	0.3	0.449	0.755
Glucose (mg/dL)	81.8	69.8	81.3	74.3	3.6	0.516	0.509
Phosphorus (mg/dL)	10.1	11.1	9.2	9.6	0.4	0.136	0.463

SEM, standard error of the mean; ALP, alkaline phosphatase; ALT, Ala transaminase; AST, Asp transaminase; BUN, blood urea nitrogen; GGT, γ-glutamyl transferase.
[1] Each least squares mean represents 4 observations.
[2] Blood samples were collected at the end of the 14-d trial.
[3] Each diet contains 0%, 15%, 30%, or 45% contaminated barley at the expense of control barley, respectively.

observed in the present study. Moreover, the reductions in ADG of pigs fed diet containing 45% contaminated barley compared with diet containing 0% contaminated barley from d 0 to 7, 7 to 14, and the overall period, were 90.3%, 70.3%, and 80.4%, respectively, which were close to the value (93.8%) predicted by the equation derived from literature data on growth performance of pigs exposed to various levels of DON (Mok et al., 2013). Considering the guidance levels of DON and ZON for swine diets at 0.9 and 0.1 mg/kg, respectively (CEC, 2006), the concentrations of

Table 8. Growth performance of pigs fed the recovery diet[1], Exp. 2

Item	Diet[2]				SEM	p-value	p-values for contrast (%)		
	Contaminated barley (%)								
	0	15	30	45			0 vs 15	0 vs 30	0 vs 45
d 0 to 7									
Initial BW (kg)	46.8	46.3	42.8	41.6	1.5	0.085	0.826	0.085	0.035
ADG (g/d)	614	1,032	589	1,086	86	0.004	0.008	0.842	0.004
ADFI (g/d)	1,976	2,281	1,804	2,110	117	0.090	0.099	0.329	0.441
G:F	0.31	0.44	0.33	0.51	0.03	0.005	0.017	0.644	0.002
Final BW (kg)	51.1	53.6	46.9	49.2	1.8	0.136	0.369	0.137	0.482
d 7 to 14									
ADG (g/d)	1,289	1,389	1,236	1,461	86	0.313	0.432	0.670	0.192
ADFI (g/d)	2,594	2,474	2,184	2,781	191	0.233	0.668	0.164	0.506
G:F	0.50	0.60	0.56	0.53	0.06	0.629	0.233	0.467	0.728
Final BW (kg)	60.1	63.3	55.5	59.4	2.2	0.174	0.340	0.175	0.828
d 0 to 14									
ADG (g/d)	952	1211	913	1273	75	0.016	0.036	0.718	0.014
ADFI (g/d)	2,285	2,378	1,994	2,445	132	0.148	0.630	0.153	0.411
G:F	0.42	0.52	0.46	0.52	0.03	0.147	0.059	0.421	0.056

SEM, standard error of the mean; BW, body weight; ADG, average daily gain; ADFI, average daily feed intake; G:F, gain:feed.
[1] Each least squares mean represents 4 observations.
[2] Each of previously fed diets contained 0%, 15%, 30%, or 45% contaminated barley at the expense of control barley, respectively.

Table 9. Vulva size of pigs fed the recovery diet[1], Exp. 2

Item	Diet[2]				SEM	p-value	p-values for contrast (%)		
	Contaminated barley (%)								
	0	15	30	45			0 vs 15	0 vs 30	0 vs 45
d 0									
Width (mm)	19.8	16.5	20.3	16.8	2.1	0.485	0.299	0.869	0.336
Length (mm)	29.3	28.3	27.5	26.8	1.6	0.721	0.666	0.455	0.294
Area[3] (mm^2)	610	471	567	448	80	0.468	0.252	0.714	0.187
d 3									
Width (mm)	27.0	26.8	28.5	28.0	2.0	0.914	0.932	0.610	0.733
Length (mm)	31.0	31.0	31.3	32.8	1.0	0.538	1.000	0.858	0.228
Area (mm^2)	840	831	892	924	88	0.856	0.944	0.685	0.512
d 6									
Width (mm)	27.5	26.8	27.8	29.5	1.8	0.735	0.771	0.923	0.445
Length (mm)	33.8	32.0	30.8	33.0	1.1	0.300	0.286	0.083	0.638
Area (mm^2)	931	857	854	974	77	0.639	0.515	0.496	0.698
d 9									
Width (mm)	27.3	28.3	29.5	29.8	1.0	0.325	0.501	0.149	0.113
Length (mm)	33.5	31.3	31.5	33.3	0.7	0.111	0.052	0.078	0.810
Area (mm^2)	915	884	929	989	42	0.401	0.614	0.816	0.246
d 12									
Width (mm)	27.3	27.0	29.5	30.5	1.1	0.139	0.877	0.187	0.069
Length (mm)	33.0	30.5	32.0	32.3	0.8	0.218	0.050	0.390	0.515
Area (mm^2)	900	824	947	984	50	0.193	0.305	0.517	0.261

SEM, standard error of the mean.
[1] Each least squares mean represents 4 observations.
[2] Each of previously fed diets contained 0%, 15%, 30%, or 45% contaminated barley at the expense of control barley, respectively.
[3] Area (mm^2) = [Width (mm)×Length (mm)]/2.

DON in the contaminated diets were above the guidance level while those of ZON were not. In addition, the vulva swelling which is one of common clinical symptoms of pigs exposed to ZON was not observed in the present study. Therefore, it might be speculated that the poor growth performance was primarily attributed to the presence of DON rather than ZON in contaminated diets fed to pigs. However, other unanalyzed *Fusarium* toxins which might interact with DON could not be excluded as a contributor for the poor growth performance. There was a linear decrease in the G:F of pigs fed diets with increasing levels of contaminated barley with *Fusarium* mycotoxins from d 0 to 7 during the first week as well as the overall period and this is in accordance with Young et al. (1983) and Smith et al. (1997) who also reported a linear reduction in the G:F as dietary DON increased in the diets. On the contrary, other studies observed a significant depression of feed intake and BW gain but no effect (Swamy et al., 2002) or an increase (Rotter et al., 1994; Swamy et al., 2003) in feed efficiency. This conflict of results among experiments may be, in part, attributed to different physiological stage of pigs (age, sex, or BW), source of contaminations (type of grains), and concentration of mycotoxins (Goyarts et al., 2005).

In contrast to the adverse effects of feeding diets contaminated with *Fusarium* mycotoxins on the growth performance, the positive effect was shown for the digestibility of DM, OM, and CP. This was in agreement with Dänicke et al. (2004a) who also found a DON-related improvement in nutrient digestibility. Several explanations could be possible for this positive effect. Matthäus et al. (2004) found that there were increased activities of protease, amylase, and non-starch polysaccharide-degrading enzymes in the wheat inoculated with *Fusarium culmorum* compared with the control wheat and were alterations of the cell penetrating properties by fungus. Reduced feed intake due to the presence of mycotoxin might also be attributed to the increase in nutrient utilization because Haydon et al. (1984) observed that the apparent total tract digestibility of DM and energy tended to increase as the feed intake of 25-kg pigs fed sorghum-SBM based diet decreased. However, Dänicke et al. (2004a) and Goyarts et al. (2005) reported that significant increases in nutrient digestibility for pigs fed diets contaminated with DON regardless of the feeding methods (i.e. *ad libitum* vs restricted) indicating that levels of feed intake did not affect nutrient digestibility.

Blood urea nitrogen is an indication of renal health and a linear increase of BUN was observed but the values were within the reference range of BUN in pigs (8.2 to 25 mg/dL; Latimer et al., 2003). Signs of liver damage (ALP, ALT, AST, and GGT) were not altered as the concentration

of mycotoxin in the diets increased. Similarly, no signs of liver damage were detected in previous studies reported (Dänicke et al., 2004a; Accensi et al., 2006) whereas other study reported that there was a dose-response related decrease in blood measurements for the sign of liver damage (Döll et al., 2003). Two major groups of blood total proteins are albumin and globulin, and their alterations are indicatives of liver damage and abnormal immune functions, respectively (Busher, 1990). In some experiments, increases of serum albumin:globulin ratio were observed in pigs fed diets containing *Fusarium* mycotoxins (Rotter et al., 1994; Swamy et al., 2003). However, there were no changes in albumin:globulin ratio as well as total protein with increasing level of contaminated barley in experimental diets used in the present study. Rotter et al. (1994) suggested that DON and other *Fusarium* mycotoxins might directly affect globulin synthesis in the liver and compromise the immune response of pigs exposed to *Fusarium* mycotoxins. This discrepancy in results might be attributed to differences in age of pigs, types of grain as mycotoxin sources, and composition of *Fusarium* mycotoxins in grains as well as volume of blood sample collected (Dänicke et al., 2004b).

Exp. 2

A rapid compensation in feed intake and BW gain of the pigs fed the corn-SBM-based standard diet for 14 days was in accordance with Dänicke et al. (2004b) who observed quick and complete growth compensatory effects. During the first week of the recovery period, feed intake of pigs previously fed contaminated diets already returned to that of pigs fed diet without contamination and this remained similar following 7 days. In addition, the difference in ADG between the pigs previously fed diets including 0 and 15% or 45% contaminated barley was significant for the period during d 0 to 7 and the overall period, which resulted in the greater G:F in the pigs previously fed diet containing 15% or 45% contaminated barley for the respective periods.

In conclusion, the present study showed that feeding of barley contaminated with *Fusarium* mycotoxin negatively affects the growth performance of pigs primarily by feed intake depression but these adverse effects were quickly recovered in 7 days after the diets were replaced to the standard corn-SBM diet. The serum immunoglobulin and blood chemical components were not altered by feeding of contaminated barley diets whereas improvement in the digestibility of DM, OM, and CP was observed and further research is needed to verify underlying mechanisms on this improvement.

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