Original Articles

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Evaluation of a mycotoxin adsorbent in swine diets containing barley naturally contaminated with *Fusarium* mycotoxins¤

Evaluación de un adsorbente de micotoxinas en dietas para cerdos que contienen cebada contaminada naturalmente con micotoxinas de Fusarium

Avaliação de um adsorvente de micotoxinas em suínos dieta contendo cevada naturalmente contaminado com micotoxinas Fusarium

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Summary

Background: contamination of barley with *Fusarium* mycotoxins causes significant economic losses for pork producers, and alleviation with mycotoxin sequestering agents has proven inconsistent. **Objective:** to evaluate a yeast cell wall product in preventing adverse effects of *Fusarium* mycotoxins on growth performance, blood characteristic, and nutrient digestibility in gilts fed diets containing barley naturally contaminated with *Fusarium* mycotoxins. **Methods:** positive and negative controls of corn-soybean meal diets containing 20% control and contaminated barley with *Fusarium* mycotoxins, respectively, were prepared. Two additional diets were prepared by adding 0.2 or 0.4% of a yeast cell wall product to the negative control diet. The experimental diets were fed to pigs with 61.7 Kg initial body weight for 2 weeks. **Results:** pigs fed the negative control diet gained less than those fed the positive control diet ($p<0.05$) from d 0 to 7 and during the overall period, but nutrient digestibility and blood characteristics were not affected by feeding the contaminated diet. Most measurements were not affected by supplementing the yeast cell wall to the negative control diet. **Conclusion:** addition of the yeast cell wall product to negative control diets failed to ameliorate the adverse effects of dietary *Fusarium* mycotoxin on growth performance.

Keywords: *deoxynivalenol, digestion, growth, yeast cell wall.*

Resumen

Antecedentes: la contaminación de la cebada con micotoxinas de *Fusarium* causa importantes pérdidas económicas para los productores de carne de cerdo, pero adsorbentes de micotoxinas para prevenir los efectos

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perjudiciales de las micotoxinas no dieron resultados consistentes. **Objetivo:** evaluar el producto de la pared celular de la levadura en la prevención de los efectos adversos de las micotoxinas de *Fusarium* sobre el crecimiento, características de la sangre, y la digestibilidad de nutrientes en cerdas jóvenes alimentadas con dietas que contienen cebada naturalmente contaminada con micotoxinas de *Fusarium*. **Métodos:** se prepararon las dietas a base de harina de maíz-soja de control positivo y negativo contienen 20% de control y cebada contaminados con micotoxinas de *Fusarium*, respectivamente. Adicionalmente se prepararon 2 dietas con productos de la pared celular de levadura de 0,2 o 0,4% a la dieta de control negativo. Fueron alimentados con las dietas experimentales cerdos con un peso corporal inicial de 61,7 Kg durante 2 semanas. **Resultados:** los cerdos alimentados con la dieta control negativo ganaron menos que aquellos alimentados con la dieta control positivo ($p<0,05$) a partir del d 0 a 7 y durante el período en general, pero la digestibilidad de los nutrientes y características de la sangre no fueron afectados por la alimentación de la dieta contaminada. La mayoría de las mediciones no fueron afectadas por la suplementación de la pared celular de la levadura con la dieta control negativo. **Conclusión:** la adición del producto de pared celular de levadura a la dieta control negativo no logró aminorar los efectos adversos de las micotoxinas de Fusarium sobre el crecimiento.

Palabras clave: *crecimiento, deoxinivalenol, digestión, pared celular de levadura.*

Resumo

Antecedentes: a contaminação da cevada com a micotoxinas *Fusarium* causa perdas econômicas significativas para os produtores de suínos, porèm os adsorventes de micotoxinas que evitam efeitos prejudiciais de micotoxinas não deram resultados consistentes. **Objetivo:** avaliar o produto da parede celular das leveduras para prevenir efeitos adversos da micotoxinas *Fusarium* no desempenho do crescimento, inchaço da vulva, característica do sangue, digestibilidade dos nutrientes em porcas jòvens que são alimentadas com dietas contendo a cevada naturalmente contaminada com micotoxinas do *Fusarium*. **Métodos:** foram preparadas dietas de controle positivo e negativo à base de milho e soja, contendo 20% do controle e cevada contaminada com micotoxinas *Fusarium*, respectivamente. Duas dietas adicionais foram preparadas complementando com 0,2 ou 0,4% o produto da parede celular das leveduras à dieta do controle negativo. As dietas experimentais foram fornecidas aos suínos com peso corporal inicial de 61,7 Kg por 2 semanas. **Resultados:** os suínos alimentados com a dieta do controle negativo ganharam menos peso do que aqueles alimentados com a dieta do controle positivo ($p<0,05$) a partir do dia 0 até 7 durante todo o período, a digestibilidade dos nutrientes e as características do sangue não foram afetadas pela alimentação da dieta contaminada. A maioria das medidas não foram afetadas pela complementação da parede celular das leveduras à dieta do controle negativo. **Conclusão:** a complementação do produto da parede celular das leveduras nas dietas de controle negativo não conseguiu melhorar o efeito adverso das micotoxinas Fusariume no desempenho de crescimento.

Palavras chave: *crescimento, desoxinivalenol, digestão, parede celular das leveduras.*

Introduction

Contamination of feed ingredients with *Fusarium* mycotoxins causes significant health problems in pigs and, consequently, economic losses for producers (Chaytor *et al.,* 2011a). *Fusarium* mycotoxins such as deoxynivalenol (DON) are frequently found in various feedstuffs and can reduce feed intake and growth, and cause immune suppression (CAST, 2003; Avantaggiato *et al.,* 2005; Jiang *et al.,* 2010).

Although barley has lower energy content than corn, it is still a good grain source for swine diets because it contains greater concentrations of crude protein (CP), lysine, and available phosphorus compared with corn (NRC, 2012; Woyengo *et al.,* 2014). However, a global survey indicated that the positive occurrence of DON in barley is 42% with average concentration being 1,677 mg/Kg, which is greater than the mycotoxin concentration guidance for swine diets, at 0.9 mg/Kg (CEC, 2006; Rodrigues and Naehrer, 2012).

The formation of DON in feedstuffs occurs at the field, prior to harvest. Under certain environmental conditions it is very difficult to completely avoid its development due to the impact of weather conditions. Thus, mycotoxin adsorbents such as yeast cell wall products (YCW) could be used to prevent the adverse effects of contaminated diets. However, their effects are still equivocal (Papaioannou *et al.,* 2002; Weaver *et al.,* 2013).

Therefore, the objective of the present study was to evaluate YCW as a mycotoxin adsorbent to prevent the adverse effects of *Fusarium* mycotoxin on growth performance, blood characteristic, and digestibility of dry matter (DM), organic matter (OM), CP, and energy for gilts fed diets containing barley naturally contaminated with *Fusarium* mycotoxins.

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.

Animals and experimental design

A total of 16 crossbred gilts averaging 61.7 Kg initial body weight (BW) (standard deviation = 5.6) were used in a 14-d study. The pigs were individually housed in metabolism crates (0.48 × 1.49 m^2) in an environmentally controlled room and were grouped by BW into four blocks and randomly assigned to four treatments in a randomized complete block design.

Ingredients, diets, feeding, and sample collection

Corn-soybean meal (SBM)-based positive control (PC) and negative control (NC) diets contained 20% of control barley and barley naturally contaminated with *Fusarium* mycotoxins, respectively. Two additional diets were prepared by supplementing 0.2 or 0.4% YCW to the NC diet (NC1 or NC2) at the expense of corn starch (Table 1). The YCW product used in the present study was an esterified glucomannan polymer extracted from the cell wall of yeast. Average daily gain (ADG), average daily feed intake (ADFI), and gain:feed (G:F) were determined based on individual BW and feed consumption measured on d 0, 7, and 14. From d 10 to 14, fecal samples were collected quantitatively using the marker to marker method (Kong and Adeola, 2014).

On d 14, blood samples were collected via the jugular vein from all the pigs using a 21-gauge needle. A 10 mL evacuated tube spray coated with K_2EDTA (BD Vacutainer® Plus Blood Collection Tubes, Becton, Dickinson and Company, Franklin Lakes, NJ, USA) was used for collecting blood samples. Blood samples for serum analysis were subsequently collected using a 5 mL evacuated tube coated with microscopic silica particles (VACUETTE® Z Serum Sep Clot Activator tube, Greiner Bio-one, Kremsmünster, Upper Austria, Austria). Collected blood samples were immediately delivered on ice to the laboratory and stored at 4 °C until centrifugation (3,500 rpm for 15 min at 4 °C). After centrifugation, a 2 mL aliquot was collected from each serum and plasma sample and stored at -20 °C for further analyses.

Table 1. Composition of experimental diets containing barley naturally contaminated with *Fusarium* mycotoxins (as-fed basis).

Item	Diet[1]			
	PC	NC	NC1	NC2
Ingredient, %				
Ground corn	50.2	50.2	50.2	50.2
Soybean meal, 48% CP[2]	27.0	27.0	27.0	27.0
Control barley	20.0	-	-	-
Contaminated barley[3]	-	20.0	20.0	20.0
Limestone	0.83	0.83	0.83	0.83
Dicalcium phosphate	0.76	0.76	0.76	0.76
Salt	0.40	0.40	0.40	0.40
Vitamin-mineral premix[4]	0.40	0.40	0.40	0.40
Corn starch	0.40	0.40	0.20	-
Adsorbent[5]	-	-	0.20	0.40
Total	100.0	100.0	100.0	100.0
Analyzed nutrient, energy, and mycotoxin				
Dry matter, %	88.7	88.7	88.6	88.7
Organic matter, %	83.9	82.9	83.2	82.8
CP, %	19.3	19.3	19.3	19.3
Metabolizable energy,[6] Kcal/Kg	3,225	3,225	3,217	3,209
Deoxynivalenol, mg/Kg	0.28	2.94	5.07	3.76

[1]PC = corn-soybean meal based diet containing 20% of control barley; NC = corn-soybean meal based diet containing 20% of contaminated barley; NC1 = NC diet supplemented with 0.2% mycotoxin adsorbent; NC2 = NC diet supplemented with 0.4% mycotoxin adsorbent.

[2]CP = crude protein.

[3]Naturally contaminated with *Fusarium* mycotoxins containing 25.7 mg/Kg deoxynivalenol.

[4]Provided the following quantities per Kg of complete diet: vitamin A, 20,000 IU; vitamin D_3, 3,200 IU; vitamin E, 40 IU; vitamin K, 4.0 mg; thiamin, 3.9 mg; riboflavin, 8.0 mg; pyridoxine, 3.9 mg; vitamin B_{12}, 0.05 mg; pantothenic acid, 30.0 mg; folic acid, 0.88 mg; niacin, 50 mg; biotin, 0.05 mg; Cu, 20 mg as copper sulfate; Fe, 214 mg as iron sulfate; I, 4.0 mg as potassium iodate; Mn, 100 mg as manganese sulfate; Se, 0.30 mg as sodium selenite; Zn, 251 mg as zinc oxide; butylated hydroxytoluene, 40 mg.

[5]Yeast cell wall product.

[6]Calculated values based on NRC (2012).

Mycotoxins and chemical analyses

Enzyme-linked immunosorbent assay kits (AgraQuant®, Romer Labs Inc., Singapore, Republic of Singapore) were used to determine the concentration of DON in the ingredients and diets. Quantification ranges for analysis on DON were from 250 to 5,000 ng/mL, respectively.

All fecal samples and orts collected from individual pigs were dried in a forced-air oven at 55 °C to constant weight. Dry matter (Ahn *et al.,* 2014) and nitrogen (method 984.13; AOAC, 2005) were determined in duplicate samples. Gross energy (GE) was determined using an isoperibol bomb calorimeter (Parr 1261 bomb calorimeter; Parr Instruments Co., Moline, IL, USA). The concentration of immunoglobulin (Ig) subsets (IgA, IgG, and IgM) in serum was determined using a Cobas Integra 800 analyzer (Roche, Mannheim, Germany). Blood chemistry measurements including albumin, globulin, total protein, alkaline phosphatase, alanine transaminase, aspartic acid transaminase, γ-glutamyl transferase, blood urea nitrogen (BUN), calcium, glucose, and phosphorus were determined on a Roche Cobas c702 automated blood chemistry analyzer (Roche, Mannheim, Germany).

Statistical analyses

Apparent total tract digestibility of DM, OM, CP, and GE was determined for each experimental diet (Kong and Adeola, 2014).

Experimental data were statistically analyzed using GLM procedures of SAS 9.2 (SAS Inst. Inc., Cary, NC, USA; 2008). Growth performance, nutrient digestibility, immunoglobulin subsets, and blood chemistry measurements were the response variables. Each animal was considered as an experimental unit. Orthogonal polynomial contrasts were used to test linear or quadratic effects of the mycotoxin adsorbent in the experimental diets, and a specific contrast was also used to compare PC and NC diets. The alpha level used for the determination of statistical differences was set at 0.05, and at 0.10 for tendencies.

Results

Mycotoxin analysis

Analyzed concentrations of DON in corn, SBM, control barley, or naturally contaminated barley were 0.6, 1.0, 0.3, or 25.7 mg/Kg, respectively. Analyzed concentrations of DON in PC, NC, NC1, or NC2 diet were 0.28, 2.94, 5.07, or 3.76 mg/Kg, respectively.

Growth performance

Pigs fed the PC diet had greater ADG and G:F ($p<0.05$) and tended to consume more feed ($p = 0.061$) compared with those fed the NC diet (Table 2) from d 0 to 7. The reduced growth performance was not recovered by the addition of the YCW except for final BW, which showed a tendency for a quadratic effect of YCW ($p = 0.056$). ADG, ADFI, and G:F were not affected by feeding the contaminated barley diet and there was no improvement in growth performance by adding the YCW to the NC diet from d 7 to 14. Pigs fed the NC diet had decreased ADG ($p = 0.025$) and tended to have decreased G:F ($p = 0.096$) compared to those fed the PC diet during the overall period.

Digestibility

Daily feed intake and nutrient digestibility were not different between PC and NC diets (Table 3). Fecal nutrient output tended to show quadratic responses ($p<0.10$) to the increasing addition of the YCW to the NC diet whereas nutrient intake and corresponding digestibility were not affected, except for CP intake, which showed a quadratic response ($p = 0.041$).

Serum immunoglobulin and blood characteristics

There was no effect of treatment on the concentrations of serum IgA, IgG, and IgM (Table 4). None of the blood chemistry measurements were altered by feeding the contaminated barley compared with the control barley, except BUN which was greater in the NC group ($p = 0.001$) compared with the PC group and showed quadratic responses to the increasing supplementation of YCW to the NC diets ($p = 0.010$).

Table 2. Growth performance of pigs fed experimental diets containing barley naturally contaminated with *Fusarium* mycotoxins.

Item[2]	Diet[1]				RMSE[3]	p-values for contrast[4]		
	PC	NC	NC1	NC2		PC vs NC	Linear	Quadratic
n	4	4	3	4				
Initial BW, Kg	62.1	62.1	63.4	61.7	-	-	-	-
d 0 to 7								
ADG, g/d	829	261	440	368	194	0.003	0.457	0.381
ADFI, g/d	2,306	1,746	1,751	1,977	364	0.061	0.395	0.676
G:F	0.36	0.13	0.26	0.18	0.10	0.011	0.528	0.168
Final BW, Kg	67.9	63.9	66.5	64.3	1.5	0.006	0.719	0.056
d 7 to 14								
ADG, g/d	832	889	698	825	262	0.765	0.737	0.409
ADFI, g/d	2,388	2,217	1,922	2,216	304	0.449	0.999	0.202
G:F	0.35	0.40	0.36	0.36	0.10	0.576	0.626	0.846
Final BW, Kg	73.7	70.1	71.4	70.1	2.5	0.075	0.978	0.487
d 0 to 14								
ADG, g/d	830	575	569	596	131	0.025	0.823	0.858
ADFI, g/d	2,347	1,981	1,837	2,097	301	0.124	0.602	0.363
G:F	0.36	0.29	0.31	0.28	0.05	0.096	0.605	0.474

[1]PC = corn-soybean meal diet containing 20% of control barley; NC = corn-soybean meal diet containing 20% of contaminated barley; NC1 = NC diet supplemented with 0.2% mycotoxin adsorbent; NC2 = NC diet supplemented with 0.4% mycotoxin adsorbent.

[2]BW = body weight; ADG = average daily gain; ADFI = average daily feed intake; G:F = gain:feed.

[3]RMSE = root mean square error.

[4]PC vs NC = contrast between the PC diet and the NC diet; Linear = linear effect of the graded concentration of the adsorbent; Quadratic = quadratic effect of the graded concentration of the adsorbent.

Table 3. Nutrients and energy digestibility of pigs fed experimental diets containing barley naturally contaminated with *Fusarium* mycotoxins.

Item[2]	Diet[1]				RMSE[3]	P-values for contrast[4]		
	PC	NC	NC1	NC2		PC vs NC	Linear	Quadratic
n	4	4	4	3				
DM intake, Kg/d	2.22	2.04	1.55	1.88	0.37	0.502	0.584	0.116
OM intake, Kg/d	2.10	1.91	1.45	1.75	0.34	0.447	0.577	0.124
CP intake, g/d	483	465	348	504	89	0.780	0.594	0.041
GE intake, kcal/d	9,974	9,045	6,968	8,409	1,643	0.447	0.634	0.130
Fecal DM output, g/d	243	237	149	184	42	0.849	0.144	0.050
Fecal OM output, g/d	206	197	126	150	36	0.752	0.132	0.071
Fecal CP output, g/d	48.3	46.3	28.8	35.3	8.9	0.766	0.152	0.065
Fecal GE output, kcal/d	1,159	1,108	708	840	200	0.727	0.125	0.069
DM digestibility, %	89.4	88.0	90.4	90.0	2.1	0.374	0.247	0.334
OM digestibility, %	90.5	89.3	91.4	91.3	1.9	0.401	0.221	0.398
CP digestibility, %	90.3	89.7	91.8	92.9	2.1	0.664	0.080	0.708
GE digestibility, %	88.7	87.4	89.8	89.8	2.3	0.417	0.198	0.411

[1]PC = corn-soybean meal based diet containing 20% of control barley; NC = corn-soybean meal based diet containing 20% of contaminated barley; NC1 = NC diet supplemented with 0.2% mycotoxin adsorbent; NC2 = NC diet supplemented with 0.4% mycotoxin adsorbent.

[2]DM = dry matter; OM = organic matter; CP = crude protein; GE = gross energy.

[3]RMSE = root mean square error.

[4]PC vs NC = contrast between the PC diet and the NC diet; Linear = linear effect of the graded concentration of the adsorbent; Quadratic = quadratic effect of the graded concentration of the adsorbent.

Table 4. Immunoglobulin and blood chemistry of pigs fed experimental diets containing barley naturally contaminated with *Fusarium* mycotoxins.

Item[2]	Diet[1]				RMSE[3]	p-values for contrast[4]		
	PC	NC	NC1	NC2		PC vs NC	Linear	Quadratic
n	4	4	3	4				
Immunoglobulin, mg/dL								
IgA	48.0	47.0	44.5	44.3	5.2	0.794	0.479	0.772
IgG	597	598	551	671	117	0.988	0.403	0.338
IgM	74.5	69.3	46.4	63.5	21.0	0.733	0.709	0.211
Blood chemistry								
Albumin, g/dL	4.50	4.53	4.91	4.45	0.40	0.931	0.796	0.163
Globulin, g/dL	2.2	1.9	1.5	2.3	0.7	0.551	0.378	0.269
Albumin:globulin	2.19	2.50	3.83	2.34	1.37	0.757	0.874	0.176
Total protein, g/dL	6.68	6.45	6.49	6.78	0.45	0.503	0.341	0.706
ALP, U/L	102	115	149	133	28	0.514	0.402	0.235
ALT, U/L	38.0	46.5	42.9	41.8	7.2	0.134	0.379	0.808
AST, U/L	37.0	53.0	47.8	84.0	26.6	0.420	0.138	0.296
GGT, U/L	33.3	50.5	33.3	56.0	15.1	0.144	0.620	0.094
BUN, mg/dL	12.5	18.1	14.0	17.0	1.5	0.001	0.364	0.010
Calcium, mg/dL	11.3	10.9	11.2	11.5	0.6	0.382	0.212	0.914
Glucose, mg/dL	84.3	66.5	70.4	60.5	15.6	0.146	0.601	0.542
Phosphorus, mg/dL	12.2	12.0	11.5	13.4	1.3	0.856	0.185	0.248

[1]PC = corn-soybean meal based diet containing 20% of control barley; NC = corn-soybean meal based diet containing 20% of contaminated barley; NC1 = NC diet supplemented with 0.2% mycotoxin adsorbent; NC2 = NC diet supplemented with 0.4% mycotoxin adsorbent.

[2]ALP = alkaline phosphatase; ALT = alanine transaminase; AST = aspartic acid transaminase; GGT = γ-glutamyl transferase; BUN = blood urea nitrogen.

[3]RMSE = root mean square error.

[4]PC vs NC = contrast between the PC diet and the NC diet; Linear = linear effect of the graded concentration of the adsorbent; Quadratic = quadratic effect of the graded concentration of the adsorbent.

Discussion

Patience *et al.* (2014) reported analyzed DON concentrations of 0.25 mg/Kg in one diet and 4.6 mg/Kg in another diet when both diets were intended to include the same level of contaminated corn distillers dried grains with solubles. Distribution of *Fusarium* mycotoxin in ingredients is more likely to be uneven because *Fusarium* species may grow spottedly and produce mycotoxins under certain storage condition. This could have contributed to the uneven distribution of mycotoxins in the contaminated diets used in the present study.

Reduction of feed intake and consequent decrease of BW gain have been commonly observed when pigs are fed DON contaminated diets (Goyarts *et al.,* 2005b; Chaytor *et al.,* 2011b; Mok *et al.,* 2013), and these were also observed in the present study. In addition, the ADFI of pigs fed the NC diet from d 0 to 7 was 24.3% less compared with those fed the PC diet, which was close to the predictive value (28.7%) of feed intake reduction calculated by the equation derived from the literature (Mok *et al.,* 2013). However, growth depression was not observed from d 7 to 14, in agreement with Waché *et al.* (2009), who reported a transient negative effect of

DON on growth performance of pigs fed diets with contaminated wheat.

Several mycotoxin adsorbing agents have been used for preventing the adverse effects of mycotoxins on pigs (Chaytor *et al.* 2011a). These products include YCW, natural clays, and cellulose products, and were evaluated through *in vitro* and *in vivo* studies (Weaver *et al.,* 2013; Kong *et al.,* 2014; Patience *et al.,* 2014). Among adsorbents, YCW products showed a particular affinity for *Fusarium* mycotoxins and are hypothesized to prevent mycotoxin absorption in the gastrointestinal tract (Huwig *et al.,* 2001; Kong *et al.,* 2014). Several studies have shown the mycotoxin prevention effects of YCW in pigs, broilers, layers, and horses (Raymond *et al.,* 2003; Swamy *et al.,* 2003; Chowdhury and Smith, 2004). However, the reduced growth of pigs fed diets containing barley contaminated with *Fusarium* mycotoxins in the present study was not recovered by adding YCW to the contaminated diets. This is in agreement with previous pig studies in which YCW products were not able to recover the adverse effects of DON contamination on growth (Swamy *et al.,* 2002; Mahan, 2010; Patience *et al.,* 2014).

The percentage of *in vitro* adsorption of aflatoxin by the YCW was 92.7%, whereas that of DON was only 22.9% (Kong *et al.,* 2014), indicating that adsorption efficacy of YCW is dependent on the type of mycotoxins (Patience *et al.,* 2014). This difference was also pronounced in previous *in vivo* studies (Avantaggiato *et al.,* 2005; Weaver *et al.,* 2013). Grenier and Applegate (2013) demonstrated that 90% of DON absorption takes place in the proximal small intestine and thus YCW does not have enough time to adsorb DON. This may be attributed to the inability of YCW to recover the reduced growth performance resulting from feeding contaminated diets.

Excretion of cell wall degrading enzymes by *Fusarium culmorum* (Kang and Buchenauer, 2000) as well as increased activity of protease, amylase, and non-starch polysaccharide-degrading enzymes in wheat inoculated with *F. culmorum* (Matthäus *et al.,* 2004) were observed. In addition, fungus protein may improve protein quality of the contaminated ingredient (Hamilton *et al.,* 1988). Several studies have reported a DON-related improvement in nutrient digestibility (Goyarts and Dänicke, 2005a). In the present study, however, feeding pigs diets with barley naturally contaminated with Fusarium mycotoxins did not have a significant effect on nutrient digestibility, in agreement with Dänicke *et al.* (2004) who reported no effect of feeding DON-contaminated diets to pigs on nutrient digestibility. The reason for this discrepancy in results is still unclear. There was a quadratic effect of YCW on CP intake and quadratic trends for nutrients output. Because DON concentration varied among contaminated diets, it was difficult to interpret the effect of YCW on nutrient digestibility. Analyzed DON concentration in NC1 and NC2 diets was 5.07 and 3.76 mg/Kg, respectively, whereas it was 2.94 mg/Kg in the NC diet. Thus, it may be speculated that relatively high DON concentrations in diets with YCW might have confounded the effect of YCW on nutrient intake and output in the present study. A similar effect was observed in a previous study in which relatively high concentration of DON (6 mg/Kg) in the glucomannan polymer supplemented diets compared to that in contaminated diet alone (4.6 mg/Kg) confounded the effect of the glucomannan polymer (Swamy *et al.,* 2002).

Inconsistent results in serum immunoglobulin subsets were observed when pigs were fed diets contaminated with *Fusarium* mycotoxins. Several studies have showed the up-regulation of serum immunoglobulin subsets in pigs fed diets containing *Fusarium* mycotoxins (Swamy *et al.,* 2002; Goyarts *et al.,* 2005b) whereas other studies showed no alteration of immunoglobulin subsets (Swamy *et al.,* 2003; Chaytor *et al.,* 2011b). In the present study, immunoglobulin subsets were not altered by feeding pigs with contaminated diets. Differences in experimental procedures, source and level of mycotoxins, as well as duration of toxin exposure might have caused the observed variation among studies (Döll and Dänicke, 2011). Blood urea nitrogen, indicative of renal health, in pigs fed the NC diet was higher than that of pigs fed the PC diet, and the pigs quadratically responded to increasing YCW levels from 0 to 0.4%. However, the values determined from all the treatments were within the reference range of BUN in pigs (8.2 to 25 mg/dL; Latimer *et al.,* 2003). Other blood serum measurements did not change by feeding the NC diet compared with the PC diet, which is in agreement with the study conducted by Cote *et al.*

(1985) who observed no alterations in hematology and serum chemistry in starter pigs fed diets containing DON (from 0.7 to 5.8 mg/Kg).

In conclusion, feeding diets containing barley naturally contaminated with *Fusarium* mycotoxins resulted in growth depression of growing gilts, whereas nutrient digestibility, immunoglobulin subsets, and blood chemistry were not affected. Furthermore, YCW supplemented to contaminated diets failed to ameliorate the negative effects of dietary *Fusarium* mycotoxins on growth performance of pigs.

Conflicts of interest

The authors declare they have no conflicts of interest with regard to the work presented in this report.

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