Effects of Different Mycotoxin Adsorbents on Performance, Meat Characteristics and Blood Profiles of Avian Broilers Fed Mold Contaminated Corn

R. J. Wang*, S. X. Fui[1], C. H. Miao and D. Y. Feng[1]
College of Agronomy and Biotechnology, China Agricultural University, Beijing 100094, P. R. China

ABSTRACT : 1,225 healthy day-old avian broiler chicks were used to investigate the effects of activated charcoal (AC, made from willow tree), hydrated sodium calcium aluminosilicates (HSCAS) and esterified glucomannan (EGM) supplementation on broiler performance, blood profiles and meat characteristics when less moldy or moldy corn was included to formulate seven isocaloric and isonitrogenous diets: Positive Control (less moldy corn diet, PC), PC+2% AC, Negative Control (moldy corn, NC), NC+0.05% EGM, NC+0.1% EGM, NC+0.5% HSCAS and NC+1% AC. PC+2% AC resulted in lower growth rate, poorer feed conversion ratio (FCR), more leg problems and higher mortality of birds than those fed PC diet ($p<0.05$). Inclusion of 0.05% EGM, 0.1% EGM, 0.5% HSCAS and 1% AC in NC diet did not improve average daily weight gain (ADG) or affect feed intake of birds during the first or the second three-week periods. However, 0.05% EGM tended to ($p>0.05$) and 0.1% EGM significantly ($p<0.05$) improved FCR during the first three-week period. Breast meat of NC birds had higher Minolta L* values (white) but lower a* (reddish) and b* (yellowish) values ($p<0.01$) than the PC birds. Addition of 0.05% EGM and 0.1% EGM in NC diet reduced the L* values ($p<0.05$), improved a* and b* values ($p<0.05$) of breast meat of birds fed NC diet, but had no effect on meat color when 0.5% HSCAS or 1% AC was included ($p>0.05$). Relative weight of liver to body was reduced by feeding NC diet ($p<0.05$) and could not be normalized by different mycotoxin adsorbents ($p>0.05$) to the ratio of the PC birds. Relative weight of cholecyst of NC birds was increased compared with PC birds and could only be normalized by addition of 0.05% EGM and 1% AC ($p<0.05$) in NC diet. NC birds had lower serum albumin level than the PC birds ($p<0.05$) and addition of 0.05% EGM or 1% AC in NC diet did normalize serum albumin level. Addition of 0.5% HSCAS in NC diet further reduced serum albumin, globulin, total protein and uric acid levels ($p<0.05$). It was concluded that lower FCR during the first three-week period of growth and deterioration of meat quality observed in bird fed moldy corn with moderate T2 and fuminisin contamination and damaged nutrients and pigment availability, might be improved by dietary supplementation of 0.05% to 0.1% EGM, but not by 1% AC or 0.5% HSCAS supplementation. ***(Asian-Aust. J. Anim. Sci. 2006. Vol 19, No. 1 : 72-79)***

Key Words : Broiler, Mycotoxin Adsorbents, Performance, Meat Characteristics, Blood Profiles

INTRODUCTION

Similar to other parts of the world (Wood, 1992; Dawson, et al., 2001; Shurson et al., 2003; Afzal and Zahid, 2004; Smith et al., 2004), mycotoxin contamination in corn and its byproducts such as dried distillers grain and solubles (DDGs) is very common in China based on mycotoxin survey in major Chinese grain and feed producing regions (Wang et al., 2003). The result suggested that unavoidable mycotoxin contamination issues demanded more attention and recognition by feed manufacturers and animal producers than they expected.

Field mycotoxicosis cases in poultry production caused by key mycotoxins such as Aflatoxin B1, Ochratoxin, T2 toxin, Zearalenone and deoxynivalenol (DON, vomitoxin) are the most notorious ones. Of the mycotoxicosis cases, acute outbreaks in modern poultry production system are rare, however, chronic and low level mycotoxin contamination through naturally contaminated grains often causes reduced production efficiency and increases susceptibility to many immune related infectious diseases (Raju and Devegowda, 2002; Surai et al., 2002; Afzal and Zahid, 2004). The molecular mechanism for mycotoxicosis is not fully understood yet. Modes such as reduced antioxidant defenses marked by reduction in glutathione perioxidase (GSH-Px) and superoxide dismutase (SOD) activities, elevated lipid peroxidation observed by increase in thiobarbituric acid reactive substances (TBARS) levels and DNA strand breaks, reduced feed intake or damaged nutrition absorption and damaged metabolism (by vomitoxin), were noted and accepted to some extent (Surai et al., 2002; Smith et al., 2004).

Many strategies have been tested in attempts to bind or absorb or degrade toxins to alleviate the toxin effect through inorganic and organic adsorbents or through nutritional manipulation methods. Tests were made by using many nutrients such as antioxidants (VA, VC, VE and Se to control tissue or cell structure damage), phenolic compounds, aspartame, piperine, coumarin and immunoglobulin to prevent mycotoxicosis (Dawson et al., 2001; Raju and Devegowda, 2002; Afzal and Zahid, 2004).

* Corresponding Author: R. J. Wang. Tel: +86-10-62733411, Fax: +86-10-62731463, E-mail: rjwang@cau.edu.cn
[1] College of Animal Science, South China Agricultural University, Guangzhou 510642, P. R. China.
Received February 22, 2005; Accepted August 5, 2005

Table 1. Formula and chemical composition of basal diets (calculated value, %)

Ingredients	0-3 week	4-6 week
Corn	52	50
Wheat	5	10.3
Soybean meal 44	28	25
Lecithin C50	6	8
Feather meal (enzyme-treated)	4.5	3.5
Limestone	1.5	1.6
$CaHPO_4$	1.65	1.2
NaCl	0.34	0.35
Premix	1	1
Chemical composition		
ME (MJ/kg)	12.80	13.10
Crude protein	21.97	20.31
Calcium	1.04	0.98
Available phosphorus	0.45	0.36
Lysine (%)	1.16	0.99
Methionine (%)	0.51	0.39

Formulated to meet NRC (1994) nutrient requirements for broiler chicken.

However, addition of adsorbents in the diet is so far the most practical method in animal production system for this purpose. These adsorbents include hydrated sodium calcium aluminosilicates (HSCAS), zeolites, bentonites, activated charcoals, probiotics such as live yeast, and yeast cell wall extract (Dawson et al., 2001; Smith et al., 2001; Raju and Devegowda, 2002). The binding efficacies of commercially available mycotoxin adsorbents for different mycotixins were different (Dawson et al., 2001; Raju and Devegowda, 2002), varying from 0 to 90%, with some being more specific to some mycotoxins and some not. Direct comparison of the effects of different mycotoxin adsorbents on broiler performance, digestibility, metabolic parameters and meat characteristics will help poultry producers objectively select effective ways to prevent mycotoxicosis and improve birds' performance and meat quality. The present study was designed to investigate the effect of activated charcoals (AC), HSCAS and modified yeast cell wall extract (esterified glucomannan, EGM) on performance, blood profiles and meat characteristics of avian broilers when moldy corn was included in the diets.

MATERIAL AND METHODS

Experimental birds

One thousand and two hundred twenty five healthy day-old broiler chicks were purchased from Beijing Dafa CP Hatchery. Upon arrival, they were divided randomly into 7 treatments of 5 pens. Each pen held 35 chicks on plastic net by weight, with *ad lib* access to fresh water and mash feed. Routine vaccination programs were followed for infectious bronchitis (IB), infectious bursal disease (IBD) and Newcastle Disease (ND). A starter diet was given in the first three weeks when the room temperature was controlled around 34-28°C and the relative humidity (RM) at 75-85%. In the second three weeks, a finisher diet was given and the room temperature was controlled around 18-25°C with RM of 75-85%. Lighting was kept for 24 h during the whole experiment.

Diets

Isocaloric and isonitrogenous corn-wheat and soy based diets were formulated for the starter and finisher phase (Table 1) to meet NRC (1994) nutrients requirement for broiler chickens by using less-contaminated (less moldy) and mycotoxin contaminated corn (moldy corn, purchased from the local grain dealer in Beijing) respectively. Basal

Table 2. Nutrient compositions of the seven treatment diets (%)

Diets	1	2	3	4	5	6	7
Treatments	PC	PC+AC 2%	NC	NC+ EGM 0.05%	NC+ EGM 0.1%	NC+ HSCAS 0.5%	NC+ AC 1%
0-3 week							
GE (MJ/Kg)	16.81	17.04	16.82	16.76	16.76	16.60	16.96
CP	22.66	22.39	22.14	22.26	22.56	21.35	22.24
Ca	1.46	1.33	1.19	1.29	1.33	1.11	1.06
Pi	0.76	0.75	0.70	0.71	0.72	0.70	0.68
Lysine*	1.16	1.16	1.16	1.16	1.16	1.16	1.16
Methionine*	0.51	0.51	0.51	0.51	0.51	0.51	0.51
4-6 week							
GE (MJ/Kg)	16.87	17.02	16.86	16.86	16.87	16.73	17.01
CP	20.70	20.46	19.86	20.79	20.85	20.34	20.14
Ca	0.96	0.98	0.99	0.99	0.99	0.99	0.98
Total P	0.58	0.57	0.63	0.63	0.63	0.63	0.62
Lysine *	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Methionine*	0.39	0.39	0.39	0.39	0.39	0.39	0.39

* Calculated values, the others were tested values.

PC = Positive control, less moldy corn; NC = Negative control, moldy corn.

AC = Activated charcoal (made from willow tree); HSCAS = hydrated sodium calcium aluminosilicates.

EGM = Esterified glucomannan; GE = Gross energy; CP = Crude protein; Ca = Calcium; P = Phosphorus.

Table 3. Effects of moldy corn and mycotoxin adsorbents on performance of broilers

Treatments	PC	PC+ AC2%	NC	NC+ EGM 0.05%	NC+ EGM 0.1%	NC+ HSCAS 0.5%	NC+AC 1%
0-3 week							
ADG (g/d)	31.03^{b}±0.74	29.10^{ab}±1.58	28.26^{a}±1.06	29.71^{b}±1.01	29.34^{ab}±0.67	29.23^{ab}±0.30	28.31^{a}±1.31
FI (g/d)	51.09^{ab}±2.89	51.68^{ab}±2.87	49.58^{ab}±1.91	49.60^{ab}±2.85	48.70^{ab}±0.93	52.24^{b}±1.57	48.65^{a}±1.91
FCR	1.64^{a}±0.06	1.78^{c}±0.08	1.75^{c}±0.06	1.67^{ab}±0.05	1.66^{ab}±0.03	1.79^{c}±0.06	1.72^{bc}±0.09
4-6 week							
ADG (g/d)	65.96^{b}±1.79	63.56^{ab}±2.32	60.95^{a}±2.17	60.80^{a} ±1.13	61.26^{a}±2.98	60.82^{a}±0.91	62.75^{ab}±2.74
FI (g/d)	130.17^{ab}±7.89	136.46^{b}±3.23	129.42^{ab}±8.08	131.04^{ab}±3.73	127.52^{a}±6.18	127.81^{a}±3.18	131.45^{ab}±4.45
FCR	1.97^{a}±0.14	2.15^{b}±0.12	2.13^{b}±0.15	2.16^{b}±0.09	2.08^{ab}±0.04	2.10^{ab}±0.08	2.10^{ab}±0.09
0-6 week							
ADG (g/d)	51.28^{b}±0.85	49.28^{a}±1.69	47.45^{a}±1.18	47.76^{a}±0.59	47.82^{a}±1.48	47.52^{a}±0.48	48.25^{a}±1.45
FI (g/d)	96.87^{ab}±5.55	100.76^{b}±1.61	95.80^{a}±4.49	96.75^{ab}±2.98	94.25^{a}±3.84	95.99^{a}±1.71	96.59^{ab}±3.01
FCR	1.89^{a}±0.08	2.05^{b}±0.06	2.02^{b}±0.09	2.03^{b}±0.07	1.97^{ab}±0.02	2.02^{b}±0.06	2.01^{b}±0.07

Values within a row with different superscripts differ significantly ($p<0.05$).

diets were divided into equal allocates after even mixing and were then remixed with designed dosage of AC, HSCAS and EGM to obtain uniform levels of mycotoxin in different diets.

The 7 treatment diets were formulated by adding different mycotoxin absorbants at specific dosage recommended by the suppliers to the basal diets. Activated charcoal (AC) made from willow tree was purchased from a local Chinese Herbal Pharmacy. It was ground to pass 20 mesh and included in the diets. HSCAS (Milwhite Houston, USA) was purchased from a local distributor. Mycosorb (EGM) was supplied by Alltech Asia Pacific Bioscience Center. The treatment design and diet information was listed in Table 2.

Measurements

Mycotoxin measurements : Ridascreen Fast-Aflatoxin, Ridascreen Fast T-2 Toxin, Ridascreen Fast-Ochratoxin, Ridascreen Fast-Fumonsin, Ridascreen Fast-Vomitoxin and Ridascreen Fast-Zearalenone (Biochemistry Trade Co. Ltd., Thailand) test kits were used in measurement of mycotoxins in the basal diets by ELISA method (Wang et al., 2003).

Production measurements : Birds were weighed at the beginning of the experiment, on day 21 and day 42 respectively. Feed intake was recorded on day 21 and day 42 for the first and second three-week periods respectively. Thus ADG, feed intake (FI) and (FCR) were determined during the first 3 weeks, the second 3 weeks and the whole 6 weeks. Daily mortality was recorded and dissection evaluation was conducted on dead birds for abnormal recordings such as beak lesions and deformed legs.

Slaughter experiment : Three healthy birds with similar weights were selected and slaughtered in every replicate at the end of the trial. Fresh weight of liver, cholecyst, spleen, bursa of fabricius and right tibia were measured. Breast meat without any obvious defect (for example damage, bleeding point and mal-pigmentation of skin) was tested for meat color via Minolta Chroma Meter II (Japan). Three points were selected randomly to test L*, a* and b* values and the respective mean value was used for statistical analysis.

Dry matter (DM), crude protein (CP), Calcium (Ca), Phosphorus (P) and ash in feed samples were analyzed via standard methods of AOAC (1990). Energy content of feed was analyzed using a PARR 1281 Bomb Calorimeter (USA).

Blood measurements : Three healthy chickens were selected randomly from every replicate of treatment 1,3,4, 6,7 at the end of the experiment. Blood samples (5 ml) were collected from vein under wings with disposable syringes and centrifuged at 3,000 r/m for 10 min to separate serum, which was stored at -20°C for analysis of total protein, uric acid, albumin, globulin, Triiodothronine (T3) and Thyroxin (T4) levels.

Serum total protein level (biuret method), albumin level (bromocresol green method) and uric acid level (by Bavaria diagnostic reagent kit, France) were tested using Olympus 600 Autoanalyzer (Japan). Serum T3 and T4 levels were determined by a commercial hospital lab (Xiyuan Chinese Medicinal Hospital) via ELISA (Bio-RAD Coda Automated EIA Analyzer) method (test kits from Beijing Northern Biotechnology Institute, China) (T3, E-62-96; T4, E-63-96).

Statistical analysis

Data in this experiment were analyzed using the one-way ANOVA procedures of SPSS 8.0. The mean differences between treatments were tested by comparison of the least significance difference.

RESULTS AND DISCUSSION

Mycotoxin contamination of the diets

In positive basal diets formulated with less moldy corn (PC diet), no detectable key mycotoxins were found. However, diets formulated with apparently moldy corn (NC

Table 4. Effects of moldy corn and mycotoxin adsorbents on leg problem incidence and mortality (%)

Treatment	Leg problems (0-6 weeks)	Mortality (0-6 weeks)
PC	0.62 ^{d}±0.26	6.36^{c}±0.34
PC+AC 2%	8.28 ^{a}±0.64	10.86 ^{a}±0.62
NC	3.70 ^{b}±0.32	8.77 ^{b}±0.57
NC+EGM 0.05%	1.58 ^{c}±0.77	6.94 ^{c}±0.39
NC+EGM 0.1%	1.41 ^{c}±0.47	6.74 ^{c}±0.33
NC+HSCAS 0.5%	2.29^{bc}±0.41	6.98 ^{c}±0.40
NC+AC 1%	1.20 ^{c}±0.36	8.67 ^{b}±0.48

Values within a column with different superscripts differ significantly ($p<0.05$).

diet) contained Aflatoxin 7.4 μg/kg, Ochratoxin 10.0 μg/kg, T-2 79.8 μg/kg, Fuminisin 700 μg/kg, Zearalenone 100 mg/kg and vomitoxin, 0.8 mg/kg. The level of mycotoxin in NC diet suggested moderate contamination for the negative control diets, especially for T2, Fuminisin, zearalenone and vomitoxin (Wang et al., 2003).

Production performance

Addition of activated charcoal (AC) at 2% dosage in PC diet formulated with less moldy corn did not significantly affect feed intake of birds during the first or second three-week trial period. However, AC addition decreased ADG ($p<0.05$) and hence affected FCR significantly ($p<0.05$). This result suggested that AC made from willow tree affected ADG not through feed intake but possibly dilution of nutrient concentration by 2%AC addition or possible nutrient binding (force feeding data with matured broiler roosters suggested less energy and protein availability when 2%AC was used in PC diet)(R. J. Wang, unpublished). Further investigation is required to understand the real mode of action.

Feed intake was not affected significantly at such mycotoxin contamination levels in broilers fed diets formulated with moldy corn (NC diet) presumed to have similar nutrition values as the unmoldy corn. However, they had lower growth rate and poorer FCR ($p<0.01$) than the positive control group (less moldy corn). This indicated that moldy corn had a lower feeding value due to mold growth or damaged nutrien absorption (indicated by forcing feeding trial that AME and CP availability were reduced in mold corn, data not shown) or mycotoxins existed. Addition of 0.05% EGM, 0.1% EGM, 0.5% HSCAS and 1% AC did not improve ADG or affected feed intake for both the first and second three-week periods. With the exception that 0.05% EGM tended to ($p>0.05$) improve and 0.1% EGM significantly ($p<0.05$) improved FCR during the first three-week period but not during the second three-week period. 0.5% HSCAS and 1% AC had no effect on FCR of birds. These results indicated that EGM especially at higher dosage was effective to help improve damaged FCR in younger birds when they were more susceptible to nutrient availability and to certain mycotoxin contaminations in nutrient absorption and metabolism that could not be detoxified by AC or HSCAS at the recommended dosages. This is possibly due to stronger and wider scope in mycotoxin binding capacity by EGM than AC or HSCAS (Devegowda et al., 1998). In feed contaminated with vomitoxin and fusaric acid (not tested in this current trial), EMG addition did significantly improve ADG and numerically improve FCR of turkeys (Smith et al., 2000). With Cobb broilers, Smith et al. (2001) also found that 4.7 mg/kg vomitoxin (when fusaric acid was about 18-22 mg/kg) did not affect ADG, feed consumption and FCR at either young or old ages, while high level vomitoxin contamination (8.3-9.7 mg/kg) did reduce ADG in finisher birds (43-56 days old), which could be overcome by addition of 0.2% EGM (Mycosorb). In this experiment, vomitoxin level (not a sensitive toxin for poultry, ruminants and cats, but sensitive for pigs and dogs, Jouany, 2001; Rumbeiha, 2001) was only 0.8 mg/kg, far lower than those tested in Smith et al. (2001). Possibly T2 and Fumonisin, which could be bound better by EGM (33.4% for T2 and 67% for Fumonisin) than AC (no known binding data) and HSCAS (11% for Fumonisin) (Devegowda et al., 1998; Dawson et al., 2001), caused detrimental effects on FCR young ages. However, such problem could be overcome by higher dosages of EGM addition in this experiment.

The mortalities of chickens (Table 4) fed PC+2% AC and NC diet (formulated with moldy corn) were higher compared with those of the PC birds ($p<0.05$), which suggested that AC at 2% dosage could be harmful for the birds even in normal diets. Feeding moldy corn caused higher mortalities as expected. Mortality was reduced by adding EGM (0.05% or 0.1%) or HSCAS (0.5%) in basal diets formulated with moldy corn. However, adding 1% AC had no effect on the mortality of birds fed diets with moldy corn.

14 birds (8.28%) in PC+2% AC diet had leg problems at the 10th day old and the severity of leg problems was reduced in elder birds. This outcome indicated that AC might have some damaging effect on the leg and caused more deaths as indexed by mortality. Force feeding metabolism trials with matured broiler roosters showed that AC, HSCAS and moldy corn reduced apparent Calcium and Phosphorus availability, which further explained that insufficient retention of Ca and P or abnormal formation of uric calcium in the joints by AC and HSCAS addition or mycotoxin might be the reason for high incidence of leg problems in young birds (Data not shown, R. J. Wang et al., 2004).

Meat characteristics

Breast meat of PC birds had lower Minolta L* values

Table 5. Effects of moldy corn and mycotoxin adsorbents on breast meat color (at 6 week old)

Treatments	PC	NC	NC+EGM 0.05%	NC+EGM 0.1%	NC+HSCAS 0.5%	NC+AC 1%
L*	50.1^{a}±2.0	55.9^{c}±0.7	53.4^{b}±1.6	53.3^{b}±0.3	54.9^{bc}±3.0	55.9^{c}±0.9
a*	11.6^{b}±0.8	9.7^{a}±0.5	10.9^{b}±0.6	9.7^{a}±0.5	9.2^{a}±0.6	8.9^{a}±0.7
b*	3.6^{c}±0.9	-0.3^{ab}±1.4	0.1^{ab}±1.1	1.2^{b}±0.7	-0.4^{ab}±0.7	-1.1^{a}±0.7

Values within a row with different superscripts differ significantly ($p<0.05$).
L* 0 = Black, L* 100 = White; a* value varies from color green to red, higher value means more reddish.
b* value varies from color blue to yellow, higher value means more yellowish.

than that of the NC birds ($p<0.01$). However, addition of 0.05% EGM and 0.1% EGM in NC diet did significantly reduce the L* values of breast meat compared with that of the NC birds. Adding HSCAS tended to reduce meat L* value and adding AC had no effect on meat L* value ($p>0.05$) in comparison with those of the NC birds. PC birds had significantly higher breast meat Minolta a* and b* values ($p<0.01$) than the NC birds. Minolta a* was improved (normalized) by adding 0.05% EGM ($p<0.05$), but not by 0.5% HSCAS or 1% AC or 0.1% EGM. Minolta b* of NC birds tend to be improved by adding 0.05-0.1% EGM ($p>0.05$) though not comparable with PC birds. Addition of 0.5% HSCAS or 1%AC in NC diet had no improvement effect over meat b* values.

Higher L value means light or pale in meat color (L* 0 = black, 100 = white). Broiler meat with L*>53 was regarded as too bright or pale, with 48<L*<53 being normal and with L*<46 being darker (Cao, 2001). In this experiment, L* value of PC birds was 50.1 and can be regarded as normal. However, NC birds (55.9), NC+0.5% HSCAS (54.9) and NC+1% AC (55.9) will be evaluated as too bright, those of NC+0.05% EGM (53.4) and NC+0.1% EGM (53.3) can be regarded as less bright and tend to be normal.

Minolta a* value represents green to red in meat color. Higher a* value means more reddish and is mainly (80%-90%) associated with higher levels of myoglobin which can be oxidized to ferric myoglobin in brown color under long term storage or too much oxidation (lower a* value). It was reported that the redness of chicken meat (a* value) could be increased by DON and fusaric acid and reduced by adding 0.2% EGM in highly contaminated corn-wheat diet (Smith et al., 2001; Smith et al., 2004). This result was different with the current experiment, which indicated that mycotoxins that caused reduced a* values by moldy corn diets in this experiment were not DON (0.8 vs. 4-8 mg/kg in Smith et al., 2001) or fusaric acid (NA vs. 20 mg/kg in Smith et al., 2001) that caused increased red value (0-1 basis) (associated with higher tested red blood cell counts and hemoglobin levels) as reported by Smith et al. (2001) study. Wu et al. (1994) also found that turkey poults fed *Fusarium* culture filtrate resulted in increasing redness in breast meat, which was suggested due to the effect of fusaric acid, a hypotensive agent that might decrease blood flow to lungs or increase oxygen trapping capacity of blood through increased red blood cell counts and hemoglobin levels. T2, DON and Fuminisin induced high lipid peroxidation could result in muscle cell membrane breakage, hence causing oxidation of myoglobin to ferric myoglobin and elevated tissue thiobarbituric acid reactive substances (TBARS) levels (Suri et al., 2002). Less protection from xanthine (a vitamin A precursor) during storage of meat in this experiment (supported by higher level of meat L* values) in birds fed moldy corn might be the cause of the lower breast a* values of NC birds observed, though more work is required to verify this observation.

Minolta b* value means the change of blue to yellow. Significant reduction in Minolta b* of birds fed moldy corn diets might result from reduced pigment retention (such as xanthine from corn) due to damage to pigments in moldy corn. Minolta b* was improved numerically by adding 0.1% EGM over NC diet but not by 0.05% EGM, 0.5% HSCAS or 1%AC. This data suggested that EGM at a higher level (more than 0.1%) might have some improvement effect on pigment absorption. More work is demanded in this field.

Meat color L* and a* values in this experiment were in the ranges of 50.1-55.9 and 9.2-11.6 respectively, and these values were in agreement with those of Lohakare et al. (2004a and 2004b) (57.76-61.06 and 9.15-11.61). However, the b* value for meat yellowness in this trial (-1.1-3.6) was much lower than those (7.3-10.2) in Lohakare et al. (2004a and 2004b), who used 7-8% corn gluten meal and more than 55% good quality corn in the diet, which should have higher xanthine content as expected. Lohakare et al. (2004b) also found that supplementation of vitamin E via feed or water both increased meat b* values and reduced muscle TBARS, which suggested less fat and pigment oxidation, i.e., more pigment retention. Therefore, pigmentation of the broiler meat (yellowness) and possible deterioration in meat color shall be concerns for specific markets when moldy corn is used in practice, when remediation such as pigment supplementation should be considered.

Organ development

Relative weight of Bursa of Fabricius, spleen or tibia to body weight was not affected by addition of different

Table 6. Effects of moldy corn and mycotoxin adsorbents on the relative weight of organ (g/100 g LBW*)

Treatment	Bursa of fabricius*	Liver	Spleen	Cholecyst	Tibia
PC	0.136 [a]±0.055	2.651 [a]±0.320	0.179 [a]±0.073	0.065 [a]±0.036	0.673 [a]±0.042
PC+AC 2%	ND	ND	ND	ND	0.727 [a]±0.128
NC	0.162 [a]±0.072	2.254 [b]±0.169	0.201 [a]±0.037	0.119 [c]±0.052	0.677 [a]±0.085
NC+EGM 0.05%	0.166 [a]±0.073	2.380 [b]±0.216	0.190 [a]±0.056	0.084 [ab]±0.030	0.728 [a]±0.083
NC+EGM 0.1%	0.178 [a]±0.081	2.319 [b]±0.210	0.198 [a]±0.067	0.098 [bc]±0.024	0.707 [a]±0.052
NC+HSCAS 0.5%	0.170 [a]±0.080	2.245 [b]±0.252	0.171 [a]±0.047	0.100 [bc]±0.029	0.737 [a]±0.055
NC+AC 1%	0.161 [a]±0.057	2.276 [b]±0.268	0.199 [a]±0.061	0.087[ab]±0.024	0.689 [a]±0.059

Values within a column with different superscripts differ significantly ($p<0.05$).
* LBW = Live body weight; ND = Not determined.

Table 7. Effect of moldy corn and mycotoxin adsorbents on serum parameters (at 6 week old)

Treatments	TP (g/L)	Albumin (g/L)	Globulin (g/L)	UA (μmol/L)	A/G	T3 (ng/Ml)	T4 (ng/mL)	T4/T3
PC	41.58 [a]±4.48	16.28 [a]±1.47	25.29 [a]±0.70	438.00 [ab]±29.9	0.646 [ab]±0.015	6.13±2.13	76.88±23.77	15.27±9.87
NC	36.85 [a]±3.90	14.19 [b]±1.00	22.66 [a]±2.97	394.23[ab]±61.01	0.661 [ab]±0.04	4.77±1.69	57.30±11.69	14.05±7.47
NC+EGM 0.05%	38.98 [a]±1.5	15.22 [ab]±0.55	23.76 [a]±1.09	459.11[a]±27.28	0.644 [ab]±0.015	3.09±1.09	57.85±13.97	20.34±6.57
NC+HSCAS 0.5%	29.10 [b]±2.63	11.70 [c]±0.93	17.40 [b]±1.73	345.31[b]±25.60	0.687 [a]±0.026	4.23±2.51	51.86±13.89	17.20±12.05
NC+AC 1%	41.22 [a]±0.95	15.60 [ab]±0.34	25.62 [a]±0.86	439.09[ab]±23.81	0.617 [b]±0.023	4.81±1.94	60.34±11.74	14.11±4.46

Values within a column with different superscripts differ significantly ($p<0.05$).
TP = Total protein, UA = Uric acid, A/G = Albumin:Globulin, T3 = Triiodothronine, T4 = Thyroxin.

mycotoxin adsorbents or moldy corn. This result is in agreement with report of Raju and Devegowda (2002) who found that T2 toxin (3 mg/kg), aflatoxin (0.3 mg/kg) and Ochratoxin (2 mg/kg) had some accumulative effect only on bursa weight and thymus weight, but not on spleen weight. However, in this experiment, relative weight of liver to body was reduced by moldy corn ($p<0.05$) and addition of different mycotoxin adsorbents could not restore the normal proportion, compared with PC diet. In contrast, relative weight of cholecyst was increased by moldy corn ($p<0.05$) and only could be restored to normal proportion by addition of 0.05% EGM and 1% AC ($p<0.05$)(Table 6).

The liver functions as a mycotoxin detoxifier, therefore its reduction in size may indicate less detoxifying capacity or damage of functions to some extent. Similar trends were found by Smith et al. (2001) who observed that high levels of DON (3.3 mg/kg) in naturally contaminated grains induced small liver weights in starter pigs significantly and could be restored to normal proportion by 0.2% EGM. Bigger cholecyst in birds fed moldy corn suggested that more bile might be required or a result to justify or combat the toxin effect.

Serum parameters

Serum albumin level (Table 7) was reduced significantly in birds fed moldy corn compared with those fed less moldy corn ($p<0.05$). However, it could be restored to normal levels by addition of 0.05% EGM and 1% AC ($p<0.05$), but not by 0.5% HSCAS. HSCAS addition in moldy corn diet further reduced serum albumin, globulin, total protein and uric acid levels significantly ($p<0.05$). These data suggested that serum albumin may be a sensitive index for mycotoxin or moldy effect investigations, but other blood parameters tested were not very sensitive due to analytical methods or actual situations. Significant reductions of albumin, globulin, uric acid and total protein in serum ($p<0.05$) were observed in birds fed NC+0.5% HSCAS, which had about 0.8% less dietary protein than the NC diet. This result indicated that HSCAS and protein level both might affect protein metabolism in broilers fed moldy corn, though the mode is not clear yet. In contrast, Smith et al. (2001) reported that broiler serum uric acid was increased significantly by high level of DON (5-10 mg/kg) and fusaric acid (17 mg/kg), and could be restored by addition of 0.2% EGM (Swamy et al., 2004). Increased serum uric acid level by DON (12 mg/kg) and fusaric acid (17 mg/kg) contamination, which was restored to normal level by 0.2% EGM, was also reported in laying hens (Smith et al., 2004). However, high level of DON (6.5-13.3 mg/kg) and fusaric acid (17 mg/kg) in turkey poults did not induce high levels of serum uric acid (Smith et al., 2004). In this experiment serum uric acid was not affected by moldy corn, or by addition of 1% AC or 0.05-0.1% EGM in comparison with PC diet. The difference in serum uric acid level changes when moldy grains were included in these experiments, indicating that variations in severity of mycotoxin contamination, poultry species or protein intake would have different effects on protein metabolism.

Serum T3 (3.09-6.13 ng/mL) and T4 (51.86-76.88 ng/mL) were only tested in 5 treatments (Table 7). No significant difference was observed among the tested groups, though PC birds had numerically higher T3 and T4 values than birds fed moldy corn ($p>0.05$). These differences may arise from variation in energy metabolism

between the less moldy corn and the moldy corn in relation to nutrient availability. This result also indicated that T3 and T4 might not be the sensitive index for mycotoxin and adsorbents investigation, or the contamination severity was not strong enough to cause significant changes in T3 or T4 levels.

CONCLUSIONS

At 2% inclusion rate, AC made from willow tree would bind or dilute nutrients and cause lower ADG, poorer FCR, more leg problems and higher mortality in birds fed diets formulated with less moldy corn. T2 toxin and fuminisin might be the key mycotoxin associated with the lower FCR, increased breast meat L* value and reduced a* value in birds fed moldy corn diets. Damage of pigments resulted in lower breast meat b* values in moldy corn diets. 0.1% EGM is more effective to adsorb mycotoxins in the moldy corn diet than 1% AC or 0.5% HSCAS in term of FCR, especially in younger birds. EGM could be more effective to improve meat color than AC or HSCAS, in normalizing L* and a* values of breast meat. Significant decrease in relative weight of liver for broilers fed moldy corn diets implied that damage of liver function in detoxification of mycotoxins. The increase in relative weight of cholecyst might mean more bile secretion was required or a result for detoxification. Adsorbents tested in the present study could not restore damaged liver of birds fed moldy corn to the normal liver to LBW ratio, with exception that supplementing 0.05% EGM and 1% AC in moldy corn could restore the enlarged cholecyst to LBW ratio to normal. Serum albumin could be a sensitive parameter to screen an effect of mycotoxin and their adsorbents. HSCAS might affect protein metabolism of broilers fed moldy corn, however the exact mode demand further investigation.

REFERENCES

Afzal, M. and A. Zahid. 2004. Effects of addition of a mycotoxin detoxifier in poultry feed containing different levels of aflatoxins on the performance of broilers. Asian-Aust. J. Anim. Sci. 17(7):990-994.

AOAC (Official Methods of Analysis). 1990. Association of Analytical Chemists. 15th Ed. Arlington, Virginia, USA.

Cao, X. W. 2001. Effect of different Se sources and level on performance, blood profiles and meat quality in broilers. MS thesis (in Chinese), Anhui Agricultural University, Hefei, PRC.

Dawson, K., J. Evans and M. Kudupoje. 2001. Understanding of adsorption characteristics of yeast cell wall preparations associated with mycotoxin binding. In: Science and Technology in the Feed Industry, Proceedings of Alltech's 17th Annual Symposium. Nottingham University Press (Ed. T. P. Lyons and K. A. Jacques), UK, pp. 169-182.

Devegowda, G., M. Raju and H. Swamy. 1998. Mycotoxins: Novel solutions for their counteraction. Feedstuffs. 12:15.

Jouany, J. P. 2001. The impact of mycotoxins on performance and health of dairy cattle. In: Science and Technology in the Feed Industry, Proceedings of Alltech's 17th Annual Symposium. Nottingham University Press (Ed. T. P. Lyons and K. A. Jacques), UK, pp. 191-224.

Lohakare, J. D., B. J. Chae and T. W. Hahn. 2004a. Effects of feeding methods (feed vs. water) of vitamin C on growth performance and meat quality of broilers. Asian-Aust. J. Anim. Sci. 17(8):1112-1117.

Lohakare, J. D., T. W. Hahn, Y. H. Shim, J. Y. Choi and B. J. Chae. 2004b. Effects of feeding methods (feed vs. water) of vitamin E on growth performance and meat quality of broilers. Asian-Aust. J. Anim. Sci. 17(9):1260-1265.

National Research Council. 1994.Nutrient Requirement of Poultry. 9th rev. Ed. National Academy Press, Washington, DC.

Raju, M. V. L. N. and G. Devegowda. 2002. Esterified-glucomannan in broiler chicken diets-contaminated with aflatoxin, ochratoxin and T2 toxin: Evaluation of its bingding ability (*in vitro*) and efficacy as immunomodulator. Asian-Aust. J. Anim. Sci. 15(7):1051-1056.

Rumbeiha, W. K. 2001. Clinical implicaton of mycotoxixosis in companion animals. In: Science and Technology in the Feed Industry, Proceedings of Alltech's 17th Annual Symposium. Nottingham University Press (Ed. T. P. Lyons and K. A. Jacques), UK, pp. 225-233.

Shurson, J., M. Spiehs, J. Wilson and M. Whitney. 2003. Value and use of a new generation distiller's dried grains with solubles in swine diet. In: Nutritional biotechnology in the feed and food industries, Proceedings of Alltech's 19th International Symposium. Nottingham University Press (Ed. T. P. Lyons and K. A. Jacques), UK, pp. 223-235.

Smith, T. K., E. J. MacDonald and S. Haladi. 2001. Current concepts in feed-borne mycotoxins and the potential for dietary prevention of mycotoxicoses. In: Science and Technology in the feed industry, Proceedings of Alltech's 17th Annual Symposium. Nottingham University Press (Ed. T. P. Lyons and K. A. Jacques), UK, pp.183-190.

Smith, T.K., S.R. Chowdhury and H. V. L. N. Swamy. 2004. Comparative aspects of fusarium mycotoxicosis in broiler chickens, laying hens and turkeys and the efficacy of a polymeric glucomannan mycotoxin adsorbent: Mycosorb. In: Nutritional Biotechnology in the Feed and Food Industries, Proceedings of Alltech's 20th Annual Symposium. Nottingham University Press (Ed. T. P. Lyons and K. A. Jacques), UK, pp. 103-109.

Swamy, H. V. L. N., T. K. Smith, P. F. Cotter, H. J. Boermans and A. E. Sefton. 2002. Effects of feeding blends of grains naturally contaminated with Fusarium mycotoxins on production and metabolism of broilers. Poult. Sci. 81:966.

Swamy, H. V. L. N., T. K. Smith, N. A. Karrow and H. J. Boermans. 2004. Effects of feeding blends of grains naturally contaminated with Fusarium mycotoxins on growth and immunological parameters of broilers. Poult. Sci. 83:533-543.

SPSS for Windows Base System Users Guide Release 8.0. Marija J. Norusis/SPSS Inc.

Surai, P. F., J. E. Dvorska, N. Sparks and K. Jacques. 2002. Impact of mycotoxins on the body's antioxidant defence. In: Nutritional Biotechnology in the Feed and Food Industries, Proceedings of Alltech's 18th International Symposium.

Nottingham University Press (Ed. T. P. Lyons and K. A. Jacques), UK, pp. 131-141.

Wang, R. J., C. H. Miao, R. Chong, N. Sawatwiroj, K. Dawson, S. X. Fu and D. Y. Feng. 2003. Survey of mycotoxin contaminations in Chinese feed ingredients. Feed Industry (in Chinese). 24(7):53-54.

Wood, G. E. 1992. Mycotoxins in foods and feeds in the United States. J. Anim. Sci. 70:3941.

Wu, W., D. Jerome and R. Najaraj. 1994. Increased redness in turkey breast meat induced by Fusarial culture materials. Poult. Sci. 73:331.