The use of distillers dried grains plus solubles as a feed ingredient on air emissions and performance from laying hens

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ABSTRACT The objectives of the current study were to evaluate the effect of feeding diets containing 0, 10, or 20% distillers dried grains plus solubles (DDGS) to laying hens (21 to 26 wk of age) on emissions of NH_3 and H_2S. Hy-Line W-36 hens (n = 640) were allocated randomly to 8 environmental rooms for a 5-wk period (hens in 3 rooms were offered the 10% and 20% DDGS diets each; hens in 2 rooms were offered the 0% DDGS diet). Diets were formulated to contain similar CP levels (18.3%), nonphytate P (0.46%), and Ca (4.2%). On an analyzed basis, the 0, 10, and 20% DDGS diets contained 0.22, 0.27, and 0.42% S. Egg weight (50.9 g), egg production (85%), and feed intake (87.9 g/hen per d) were unaffected by diet ($P > 0.05$) over the study period. Daily NH_3 emissions from hens fed diets containing 0, 10, and 20% DDGS were 105.4, 91.7, and 80.2 mg/g of N consumed, respectively ($P < 0.05$). Daily H_2S emissions from hens fed commercial diets containing 0, 10, and 20% DDGS were 2.6, 2.4, and 1.1 mg/g of S consumed, respectively. Overall, feeding 21- to 26-wk-old laying hens diets containing 20% DDGS decreased daily NH_3 emissions by 24% and H_2S emissions by 58%. Each hen emitted approximately 280 mg of NH_3 and 0.5 mg of H_2S daily when fed a control diet containing 18% CP and 0.2% S. The results of this study demonstrate that 20% DDGS derived from ethanol production can be fed to laying hens, resulting in lower emissions of NH_3 and H_2S with no apparent adverse effects on hen performance.

Key words: ammonia, distillers dried grains plus solubles, hydrogen sulfide, laying hen, egg production

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INTRODUCTION

Distillers dried grains plus solubles (**DDGS**) is a coproduct of the beverage and ethanol industries that has been used in livestock and poultry diets for decades. Matterson et al. (1966) indicated that laying hens fed 0, 10, and 20% beverage industry-derived DDGS did not change egg production. Studies have shown that inclusion of 20% DDGS can improve growth performance of broilers when diets are balanced for energy and lysine (Waldroup et al., 1981). A 40% replacement of soybean meal protein with DDGS protein had no effect on chick BW when lysine was equalized (Parsons et al., 1983). Recently, due to the large increase in ethanol production from corn, DDGS derived from ethanol production has become a more readily available ingredient for livestock and poultry diets. Numerous studies have been conducted to evaluate the DDGS resulting from newer ethanol production technologies as an alternative ingredient (Whitney et al., 2001; Noll et al., 2002; Martinez Amezcua et al., 2004; Lumpkins et al., 2005). Lumpkins et al. (2005) suggested that DDGS can be used as an acceptable feed ingredient for laying hen diets and recommended a maximal inclusion level of 10 to 12% DDGS for commercial diets. Roberts et al. (2007) indicated that a diet containing 10% DDGS lowered NH_3 emission from laying hen manure. However, there is little information on use of higher levels (>10%) of DDGS on gaseous emissions. The current study was conducted to evaluate the effect of feeding laying hens commercial-type diets containing 0, 10, and 20% DDGS on emissions of NH_3 and H_2S.

MATERIALS AND METHODS

Experimental Birds and Design

Experimental procedures were approved by the Iowa State University Committee for the Care and Use of Animals. Hy-Line W-36 hens (n = 640, initial BW = 1.90 kg, initial age = 21 wk) were obtained from Rose Acres Farms (Seymour, IN) for this 5-wk study. All

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Table 1. Diet and nutrient composition (as-fed basis) of the diets containing 0, 10, or 20% distillers dried grains plus solubles (DDGS)

Item	0% DDGS	10% DDGS	20% DDGS
Ingredient, %			
Corn	51.75	46.36	40.97
DDGS	0.00	10.00	20.00
Soybean meal (48% CP)	29.16	24.48	19.80
Soy oil	5.63	5.72	5.81
Sodium chloride	0.41	0.37	0.33
DL-Met	0.20	0.19	0.18
L-Lys·HCl	0.00	0.08	0.16
Limestone	9.71	9.81	9.92
Dicalcium phospate	1.79	1.64	1.48
Vitamin-mineral premix[1]	0.35	0.35	0.35
Celite[2]	1.00	1.00	1.00
Calculated nutrient composition			
ME, kcal/kg	2,948	2,948	2,948
CP, %	18.30	18.30	18.30
Ca, %	4.20	4.20	4.20
Total P, %	0.69	0.70	0.71
Nonphytate P, %	0.46	0.46	0.46
Met, %	0.48	0.48	0.48
Lys, %	0.99	0.99	0.99
TSAA, %	0.79	0.80	0.80
Analyzed composition, %			
CP	18.63	18.61	18.67
Total P	0.63	0.66	0.71
Ca	4.67	4.57	4.10
S	0.23	0.28	0.30
Met	0.46	0.45	0.46
Lys	1.06	1.06	1.04

[1]Vitamin mineral premix provided the following (per kg of diet): vitamin A, 12,320 IU; vitamin D, 4,620 IU; vitamin E, 15.4 IU; vitamin K, 3.1 mg; riboflavin, 6.2 mg; pantothenic acid, 15.4 mg; niacin, 46.3 mg; menadione sodium bisulfate complex, 1.0 mg; choline chloride, 463.1 mg; folic acid, 0.3 mg; vitamin B_{12}, 23.1 µg; Zn from zinc oxide, 71.4 mg; Fe from ferrous sulfate, 50.4 mg; Mn from manganese oxide, 89.6 mg; Cu from copper sulfate, 7 mg; I from ethylene diamine dihydroiodide, 0.7 mg; and Se from sodium selenite, 0.25 mg.

[2]Celite Corporation, Lompoc, CA.

hens were moved to the research location 3 d before the start of the study and allocated randomly to 1 of 8 environmental rooms. In each room, 80 birds were divided between 8 cages (10 birds/cage, 355 cm^2 of cage-floor space/bird).

Diets and Management

The experiment was designed with 3 treatments in which DDGS was included in the commercial diet at 0, 10, and 20%, respectively, replacing corn and soybean meal. All diets were formulated to meet or exceed NRC (1994) nutrient recommendations for laying hens. Composition of experimental diets is shown in Table1. The diet containing 0% DDGS (control) was assigned randomly to 2 of the 8 rooms and diets containing 10 or 20% DDGS were assigned randomly to the remaining 6 rooms (3 rooms per diet), with room constituting the experimental unit. Hens were provided ad libitum access to water via nipples and to feed. Feed (approximately 95 g/hen per d) was offered twice daily (0600 and 1600 h) and feed intake was recorded weekly from each room. Temperatures in all chambers were maintained at 22 ± 2°C. The humidity ranged from 20 to 80% over the course of the 5-wk study period. Light (10 to 20 lx) was provided from 0600 to 2200 h.

Hens were weighed at the beginning and end of the study. Change in BW was calculated by subtracting initial from ending room BW. Average feed intake for each room was calculated based on that week's total feed consumption divided by 7 d and number of birds. Eggs were collected daily from each room and egg numbers as well as total egg weight were recorded.

Measurement of Gaseous Concentrations

Eight rooms (2.14 × 3.97 × 2.59 m, height × width × length) were designed to continuously monitor incoming and exhaust concentrations of NH_3, H_2S, NO, NO_2, and SO_2 as described previously (Wu-Haan et al., 2007). Ammonia was measured using a chemiluminescence NH_3 analyzer (model 17 C, Thermal Environmental Instruments, Franklin, MA), which is a combination NH_3 converter and NO-NO_2-NO_x analyzer. Hydrogen sulfide was analyzed using a pulsed fluorescence SO_2-H_2S analyzer (model 45C, TEI, Franklin, MA). As described previously (Wu-Haan et al., 2007), through software control, gaseous concentration monitoring of each room occurred in a sequential manner. Cumulative emissions of NH_3 and H_2S were calculated daily by summing the mass emitted during each period for that day (10 to 11 daily measurements per room).

Table 2. Egg weight, egg production, feed intake, and BW change data in 21- to 26-wk-old laying hens fed diets containing 0, 10, or 20% distillers dried grains plus solubles (DDGS)[1]

Diet	Egg weight, g	Egg production, %	Feed intake, g/hen per d	Total feed intake, kg/hen	BW change, g/hen
0% DDGS	50.7	85.0	87.7	219.6	−492.7
10% DDGS	50.7	85.1	88.0	214.8	−509.3
20% DDGS	50.5	84.8	88.1	215.9	−486.9
SEM	0.1	0.1	1.3	3.3	12.6
Probability of diet effect	0.70	0.17	0.97	0.22	0.24

[1]Means represent 2 to 3 replicate rooms per diet, 80 birds per room at the start of the trial.

Chemical Analyses

Feed samples were collected weekly and pooled to produce a single composite sample of each diet. Feed N content was determined using the Kjeldahl method (method 928.08; AOAC International, 2000). Total P was measured using a colorimetric molybdovanadate procedure (method 965.17; AOAC International, 2000) and a Hach DR/4000 spectrophotometer (Hach Company, Loveland, CO). Sulfur and Ca were analyzed by the forage testing laboratory at Dairy One (Dairy One Inc., Ithaca, NY) using a wet chemistry inductively coupled plasma spectroscopy method.

Statistical Analysis

Hen performance data were analyzed using a GLM procedure (SAS Institute, 2002). The model tested the fixed effects of diet. Emissions data were analyzed using a MIXED procedure of SAS (SAS Institute, 2002). The model tested the fixed effects of diet with day as a random variable. Significant differences among the means were declared at $P \leq 0.05$.

RESULTS AND DISCUSSION

Hen Performance

Feeding hens diets containing up to 20% DDGS had no significant effect on egg weight (50.6 g), egg production (85.0%), daily feed intake (87.9 g/hen), or BW change in hens between 21 to 26 wk of age (Table 2). Similar results were reported by Lumpkins et al. (2005), in which no difference in egg weight (46.6 and 46.5 g), egg production (84.1 and 83.6%), and feed intake (83 and 84 g/hen per d) in Hy-Line W-36 laying hens aged 22 to 26 wk were observed when 0 and 15% DDGS were incorporated into a commercial diet. There were no differences in mortality between the treatments and mortality rate was 0.9%.

Significant BW loss was observed in hens fed all diets. The reason for this is not clear. The decrease of BW may have been related to cage space or stage of development. However, the average weights of 21-wk-old hens (1.9 kg) at the beginning of trial were higher than the commercial guideline target BW (Hy-Line International, 2009) for Hy-Line W-36 laying hens (suggested target BW = 1.4 kg) and the average weight of 26-wk-old hens at the end of trial was at target BW (1.5 kg) for this age.

NH_3 Emissions

A decrease in daily mass of NH_3 emitted, adjusted per gram of N consumed, was observed ($P < 0.01$) as the amount of DDGS increased from 0 to 20% (Table 3). Daily NH_3 emissions from hens fed diets containing 0, 10, and 20% DDGS were 105.4, 91.7, and 80.2 mg/g of N consumed, respectively. Across diets, an average 8 to 10% of the N consumed was emitted in the form of NH_3 gas. Daily emissions of NH_3 adjusted for feed intake from hens fed the 20% DDGS diet (2.4 mg/g of feed intake) were less than those from hens fed the 0 and 10% DDGS diets (3.1 and 2.7 mg/g of feed intake, respectively).

Table 3. Average daily emissions of NH_3 from 21- to 26-wk-old laying hens fed diets containing 0, 10, or 20% distillers dried grains plus solubles (DDGS)[1]

Diet	Concentration, mg/kg	ER,[2] mg/min	Daily mass, mg	EF,[3] mg/kg of BW	EF, mg/bird	EF, mg/g of egg mass	EF, mg/g of feed intake	EF, mg/g of N intake
0% DDGS	5.4[a]	15.6[a]	22,027[a]	169.9[a]	276.9[a]	6.0[a]	3.1[a]	105.4[a]
10% DDGS	5.6[a]	13.7[a]	19,326[a]	142.9[a]	243.0[a]	5.4[a]	2.7[a]	91.7[b]
20% DDGS	4.1[b]	11.9[b]	16,801[b]	125.2[b]	212.9[b]	4.6[b]	2.4[b]	80.2[c]
SEM	0.4	1.3	1,783	13.2	22.5	0.4	0.3	0.2
Probability of diet effect	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a–c]Means within a column lacking common superscripts differ ($P < 0.05$).

[1]Means represent 2 to 3 replicate chambers per diet, 10 to 11 observations per day, and 80 birds per room at the start of the trial.

[2]ER = emission rate by room.

[3]EF = emission factor.

Table 4. Average daily emissions of H_2S from 21- to 26-wk-old laying hens fed diets containing 0, 10, or 20% distillers dried grains plus solubles (DDGS)[1]

Diet	Concentration, mg/kg	ER,[2] mg/min	Daily mass, mg	EF,[3] mg/kg of BW	EF, mg/bird	EF, mg/g of egg mass	EF, mg/g of feed intake	EF, mg/g of S intake
0% DDGS	0.0040[ab]	0.031[a]	43.06[a]	0.32[a]	0.54[a]	0.0133[a]	0.0062[a]	2.6[a]
10% DDGS	0.0047[a]	0.031[a]	44.32[a]	0.33[a]	0.56[a]	0.0136[a]	0.0064[a]	2.4[b]
20% DDGS	0.0034[b]	0.024[b]	34.64[b]	0.26[b]	0.44[b]	0.0101[b]	0.0049[b]	1.2[c]
SEM	0.0002	0.002	2.10	0.02	0.02	0.0007	0.0003	0.1
Probability of diet effect	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a–c]Means within a column lacking common superscripts differ ($P < 0.05$).

[1]Means represent 2 to 3 replicate chambers per diet, 10 to 11 observations per day, and 80 birds per room at the start of the trial.

[2]ER = emission rate by room.

[3]EF = emission factor.

On a per-bird basis, daily NH_3 emissions from hens consuming diets containing 0, 10, and 20% DDGS were 276.9, 243.0, and 212.9 mg/bird per day, respectively (Table 3). Including 20% DDGS in the diet resulted in lower NH_3 emissions compared with the 0 or 10% DDGS diets. Daily NH_3 emissions from hens fed the control diet (0% DDGS added) were in agreement with earlier findings (Wu-Haan et al., 2007), which showed daily NH_3 emissions of 255 mg/bird from hens (Hy-Line W-36 hens aged from 21 to 24 wk) consuming a similar commercial diet. These data suggest that emissions from 21- to 26-wk-old Hy-Line W-36 layers likely range from 250 to 280 mg of NH_3 per day when fed a typical commercial diet containing 18% CP.

Average daily emissions of NH_3 adjusted for BW from hens fed diets containing 0, 10, and 20% DDGS were 169.9, 142.9, and 125.2 mg/kg of BW, respectively (Table 3). Values were similar to an earlier study conducted by Wu-Haan et al. (2007), who reported daily NH_3 emissions of 183.0 mg/kg of BW from Hy-Line W-36 hens consuming a similar diet. These findings suggest that for every 1 kg of hen live weight, 170 to 180 mg of NH_3 is emitted daily when a typical commercial diet (18% CP) is fed.

Calculation of NH_3 emissions based on egg mass produced showed that hens fed the 0% DDGS diet (6.0 mg/g of egg mass) and 10% DDGS diet (5.4 mg/g of egg mass) emitted more NH_3 than hens fed the 20% DDGS diet (4.6 mg/g of egg mass). For each 50-g egg laid, approximately 300 mg of NH_3 was emitted when a commercial diet was fed. Similar findings were observed for daily NH_3 emissions rate and mass (Table 3).

Overall, the results indicate that feeding laying hens a diet containing 20% DDGS can decrease NH_3 emissions (mg/g of N consumed) by 24%. In a manure storage study, Roberts et al. (2007) demonstrated reduced NH_3 emissions in excreta obtained from hens fed a 10% corn DDGS diet. They speculated that reduced NH_3 emissions were likely due to reduced manure pH as a result of increased short-chain fatty acids in manure caused by microbial fermentation of the dietary fermentable fiber. Researchers have found that the end products (volatile fatty acids) of microbial fermentation of dietary fermentable fiber in pigs (Farnworth et al., 1995), rats (Younes et al., 1995), and humans (Hara et al., 1994) decrease fecal and slurry pH, which results in lower NH_3 emissions (Canh et al., 1998; Sutton et al., 1999). Excreta pH and fatty acid content were not measured in the present study, therefore not allowing for confirmation of the theory.

H_2S Emissions

A decrease in daily mass of H_2S emitted, adjusted per gram of S consumed, was observed ($P < 0.01$) as the amount of DDGS increased from 0 to 20% (Table 4). Daily H_2S emissions from hens fed diets containing 0, 10, and 20% DDGS were 2.6, 2.4, and 1.1 mg/g of S consumed, respectively. Daily emissions of H_2S adjusted for feed intake from hens fed the 20% DDGS diet

Table 5. Average daily emissions of NO, NO_2, and SO_2 from 21- to 26-wk-old laying hens fed diets containing 0, 10, or 20% distillers dried grains plus solubles (DDGS)[1]

	NO emissions		NO_2 emissions		SO_2 emissions	
Diet	ER,[2] mg/min	Daily mass,[3] mg	ER, mg/min	Daily mass, mg	ER, mg/min	Daily mass, mg
0% DDGS	0.05	69.8	0.29	417.6	0.001	1.67
10% DDGS	0.06	63.7	0.27	444.5	0.002	3.53
20% DDGS	0.05	79.4	0.30	431.8	0.002	2.21
SEM	0.01	14.1	0.02	36.4	0.0004	0.58
Probability of diet effect	0.20	0.20	0.10	0.10	0.10	0.10

[1]Means represent 2 to 3 replicate chambers per diet, 10 to 11 observations per day, and 80 birds per room at the start of the trial.

[2]ER = emission rate by room.

[3]On a per-room basis.

(0.0049 mg/g of feed consumed) were less than from hens fed the 0 and 10% DDGS diets (0.0062 and 0.0064 mg/g of feed consumed, respectively). There was no statistical difference in emissions of H_2S between hens fed the 0 or 10% DDGS diets.

On a per-bird basis, daily H_2S emissions from hens consuming diets incorporating 0, 10, and 20% DDGS were 0.54, 0.56, and 0.44 mg/bird, respectively (Table 3). Including 20% DDGS in the layer diet resulted in reduced H_2S emission compared with 0 or 10% DDGS inclusion levels. This compares to data reported by Wu-Haan et al. (2007), who showed daily H_2S emissions of 0.5 mg/bird from Hy-Line W-36 hens aged from 21 to 24 wk consuming a diet similar to the 0% DDGS diet in this study (0.25% dietary S).

Average daily emissions of H_2S adjusted for BW from hens fed diets containing 0, 10, and 20% DDGS were 0.32, 0.33, and 0.26 mg/kg of BW (Table 3). The emission factor was similar to the value reported by Wu-Haan et al. (2007; 0.32 mg/kg of BW). Results suggest that for every 1 kg of hen live weight, 0.3 mg of H_2S is emitted daily when a typical commercial diet is fed.

Calculated emissions of H_2S based on egg mass produced were higher when hens were fed the 0% DDGS diet (0.0133 mg/g of egg mass) and the 10% DDGS diet (0.0136 mg/g of egg mass) compared with hens fed the 20% DDGS diet (0.0101 mg/g of egg mass) (Table 3). Similar results were found when calculated as daily H_2S emissions rate. Mass of H_2S emitted was less from hens fed the 20% DDGS than from hens fed the 0 or 10% DDGS diets. Thus, for each egg produced (average 50-g egg), approximately 0.7 mg of H_2S was emitted across the 3 diets fed.

Overall, feeding the diet containing 20% DDGS to laying hens between 21 and 26 wk of age reduced daily H_2S emitted (mg/g of S consumed) by 58% compared with emissions from hens fed diets containing 0 to 10% DDGS. The reason for this is unclear; however, S balance reported in a companion paper (Wu-Haan et al., unpublished data) demonstrated that S content in excreta from hens fed the 20% DDGS diet increased, suggesting that volatilization of S was lower. Reduced volatilization may have been due to a higher pH in excreta from hens fed the 20% DDGS diet; however, this is contrary to the possible rationale for reduced NH_3 emissions when hens were fed the 20% DDGS diet, suggesting that a different mechanism is responsible.

No diet effects on emissions of NO, NO_2, and SO_2 were observed in the current study (Table 5). Data are provided as a means of providing baseline emissions of NO, NO_2, and SO_2 in the literature and to document the importance of these gasses relative to other emissions from laying hen facilities.

In conclusion, daily emissions of NH_3 and H_2S from 21- to 26-wk-old laying hens decreased when DDGS was included in the diet at 20%. Overall, the results suggest that feeding a diet containing 20% DDGS could decrease NH_3 emissions (mg/g of N intake) by 24% and H_2S emissions (mg/g of S intake) by 58%. The effect of feeding higher DDGS to laying hens on long-term emissions from stored manure, however, remains to be determined.

REFERENCES

AOAC International. 2000. Official Methods of Analysis of AOAC International. 17th ed. AOAC Int., Gaithersburg, MD.

Canh, T. T., A. L. Sutton, A. J. A. Aarnink, M. W. A. Verstegen, J. W. Schrama, and G. C. M. Bakker. 1998. Dietary carbohydrates alter the fecal composition and pH and the ammonia emission from slurry of growing pigs. J. Anim. Sci. 76:1887–1895.

Farnworth, E. R., H. W. Modler, and D. A. Mackie. 1995. Adding Jerusalem artichoke (*Helianthus tuberosus* L.) to weaning pig diets and the effect on manure composition and characteristics. Anim. Feed Sci. Technol. 55:153–160.

Hara, H., S. Li, M. Sasaki, T. Maruyama, A. Terada, Y. Ogata, K. Fujita, H. Ishigami, K. Hara, I. Fujimori, and T. Mitsuoka. 1994. Effective dose of lactosucrose on fecal flora and fecal metabolites of human. Bifidobacteria Microflora 13:51–63.

Hy-Line International. 2009. Hy-Line W-36 Commercial Management Guide 2009–2011. Hy-Line International, West Des Moines, IA.

Lumpkins, B. L., A. B. Batal, and N. M. Dale. 2005. Use of distillers dried grains plus solubles in laying hen diets. J. Appl. Poult. Res. 14:25–31.

Martinez Amezcua, C., C. M. Parsons, and S. L. Noll. 2004. Content and relative bioavailability of phosphorus in distillers dried grains with solubles in chicks. Poult. Sci. 83:971–976.

Matterson, L. D., J. Tlustohowicz, and E. P. Singsen. 1966. Corn distillers dried grains with solubles in rations for high-producing hens. Poult. Sci. 45:147–151.

Noll, S. L., V. Strangeland, G. Speers, C. Parsons, and J. Brannon. 2002. Utilization of canola meal and distillers grains with solubles in market turkey diets. Poult. Sci. 81(Suppl. 1):92. (Abstr.)

NRC. 1994. Nutrient Requirements of Poultry. 9th rev. ed. National Academy Press, Washington, DC.

Parsons, C. M., D. H. Baker, and J. M. Harter. 1983. Distillers dried grains with solubles as a protein source for the chick. Poult. Sci. 62:2445–2451.

Roberts, S. A., H. Xin, B. J. Kerr, J. R. Russell, and K. Bregendahl. 2007. Effects of dietary fiber and reduced crude protein on ammonia emission from laying-hen manure. Poult. Sci. 86:1625–1632.

SAS Institute. 2002. Version 9.1. SAS Institute Inc., Cary, NC.

Sutton, A. L., K. B. Kephart, M. W. A. Verstegen, T. T. Canh, and P. J. Hobbs. 1999. Potential for reduction of odorous compounds in swine manure through diet modification. J. Anim. Sci. 77:430–439.

Waldroup, P. W., J. A. Owen, B. E. Ramsey, and D. L. Whelchel. 1981. The use of high levels of distillers dried grains with solubles in broiler diets. Poult. Sci. 60:1479–1484.

Whitney, M. H., M. J. Spiehs, and G. C. Shurson. 2001. Availability of phosphorus in distillers dried grains with solubles for growing swine. J. Anim. Sci. 79(Suppl. 1):108. (Abstr.)

Wu-Haan, W., W. J. Powers, C. R. Angel, C. E. Hale III, and T. J. Applegate. 2007. Effect of an acidifying diet combined with zeolite and slight protein reduction on air emissions from laying hens of different ages. Poult. Sci. 86:182–190.

Younes, H., C. Demigne, S. Behr, and C. Remesy. 1995. Resistant starch exerts a lowering effect on plasma urea by enhancing urea N transfer into the large intestine. Nutr. Res. 15:1199–1210.