Including Fiber in the Diet of Laying Hens Lowers Ammonia Emission

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Summary and Implications

Lowering ammonia emission from large-scale laying-hen operations is becoming an important issue facing the poultry industry. In this experiment, corn distiller's dried grains with solubles (**DDGS**), wheat middlings, or soybean hulls were added to laying-hen diets to determine the effect of dietary fiber on manure ammonia emission. Results show that addition of any of the three types of dietary fiber lowers total manure ammonia emission by up to 50% without adversely affecting egg production.

Introduction

The development of a sustainable, profitable, and competitive egg-production system is becoming a challenging issue facing the laying-hen industry. The excretion and volatilization of nitrogen is responsible for a large part of the environmental issues that have risen from intensive poultry production. Federal government regulations require reporting of ammonia release greater than 100 pounds per day from a single source. The Occupational Safety and Health Administration (**OSHA**) and the United Egg Producers' Animal Husbandry Guidelines have set maximum ammonia atmospheric concentration exposure limits at 50 ppm for humans and laying hens, respectively. Maintaining atmospheric ammonia concentrations below 50 ppm is difficult in high-rise laying-hen houses, especially during winter when ventilation is decreased and ammonia concentrations may rise above 100 ppm. Therefore, egg producers need methods of lowering emissions while maintaining egg production.

Addition of fermentable fiber to pig diets lowers ammonia emission by shifting nitrogen excretion from urine (in the form of urea) to the feces (in the form of bacterial protein). This shift occurs because the pig cannot digest dietary fiber; consequently, the fiber is available as an energy source for bacteria residing in the large intestines. In addition to energy, the bacteria need nitrogen for protein synthesis, of which part comes from nitrogen in the blood that would otherwise be excreted as urea (uric acid in poultry). Therefore, less nitrogen is excreted in the urine and more in the feces. Although the total amount of nitrogen excreted may not change, the form in which it is excreted does (i.e., urea vs. bacterial protein). Bacterial protein is more stable compared to urea or uric acid and is less likely to be converted to ammonia after excretion.

Additionally, bacterial fermentation of fiber in the large intestine produces short-chain fatty acids, which are excreted in the manure. These short-chain fatty acids lower the pH of the manure, converting ammonia (NH_3) to the more water-soluble ammonium (NH_4^+), which results in lower ammonia emission into the air.

The objective of this trial was to determine if addition of fermentable fiber to laying-hen diets would lower ammonia emission, similar to the effects shown in pigs, by shifting nitrogen excretion from uric acid to more stable bacterial protein and by lowering manure pH.

Materials and Methods

A total of 256 Hy-Line W-36 hens, 23 weeks of age, were used for this trial. The four diets included a corn- and soybean meal-based control diet and diets formulated with 10.0% corn DDGS, 7.3% wheat middlings, and 4.8% soybean hulls (Table 1). The wheat middlings and soybean hulls were included in the respective diets to supply equal amounts of neutral detergent fiber as the 10.0% corn DDGS. Diets were formulated to contain equal quantities of digestible amino acids and metabolizable energy and contained Celite™ as a source of acid-insoluble ash, used as an indigestible marker. Hens were housed two per cage (corresponding to 96 in^2 per hen) and each cage was equipped with one nipple drinker and a plastic self-feeder. Hens were phase-fed to account for changes in feed intake and nutrient requirements; results from Phase 3 (45 to 58 weeks of age) are reported here.

Six weeks into the phase, manure was collected from each cage and analyzed for contents of total nitrogen, uric acid, acid insoluble ash, and pH. Total manure and nitrogen excretion were calculated using acid insoluble ash as an indigestible marker. To obtain sufficient manure for ammonia-emission analysis, manure from cages receiving the same dietary treatment was collected over three consecutive 24-hour periods, pooled by diet within period, and stored at –20˚C until analysis of ammonia emission over 7 days in ammonia-emission vessels. Nitrogen balance was calculated using the nitrogen contents of feed, eggs, and manure. Apparent fecal nitrogen and dry matter digestibilities were also calculated using acid-insoluble ash as an indigestible marker. Egg production was recorded daily, whereas feed consumption (measured as feed disappearance) and egg weight were measured weekly. Egg mass (calculated as egg production × egg weight) and feed utilization (egg mass / feed consumption) were calculated weekly. During week 4 of the phase, egg yolk color and egg composition (contents of solids, yolk, albumen, and shell) were measured as indicators of egg quality.

Data were analyzed by analysis of variance (**ANOVA**) appropriate for a randomized complete block design with 32 replications; the model included the effects of block, fiber, protein, and the interaction of protein and fiber. Data from the fiber treatments were compared to those of the control using contrasts.

Results and Discussion

Ammonia emission was lowered ($P < 0.01$) by up to 50% from the manure of hens fed corn DDGS, WM, or SH compared to ammonia emission from manure of hens fed the control diet (Figure 1). Additionally, each of the treatments resulted in a decrease in the ammonia-emission rate from the manure compared to the control diet (Figure 2). The top layer of a manure stack, such as is found in a high-rise laying-hen house, is principally responsible for ammonia emission. Because manure is continually added to the stack, the ammonia-emission rate during the first few days after excretion and before manure becomes buried, is extremely important. Additionally, in manure-belt houses, the ammonia-emission rate determines the amount of nitrogen lost during the 1 to 3 days after manure excretion and before removal of manure from the house. Once the manure is removed to a storage building, it can be treated to minimize further ammonia loss by minimizing surface area to volume ratio or applying chemical treatments. The lower daily ammonia-emission rate indicates that feeding high-fiber diets such as those fed in this study in a commercial setting would cause more nitrogen to be retained in the manure in either a high-rise or manure-belt laying-hen house where manure is most susceptible to ammonia volatilization for the first few days after excretion.

To determine if the addition of dietary fiber caused a repartitioning of nitrogen excretion from uric acid to bacterial protein, the uric acid content of manure was measured and calculated as uric acid nitrogen as a percentage of total nitrogen excretion. However, there were no differences ($P > 0.10$) in uric acid nitrogen as a percentage of total nitrogen in the manure from the fiber-fed hens compared to manure from the hens fed the control diet (Table 2).

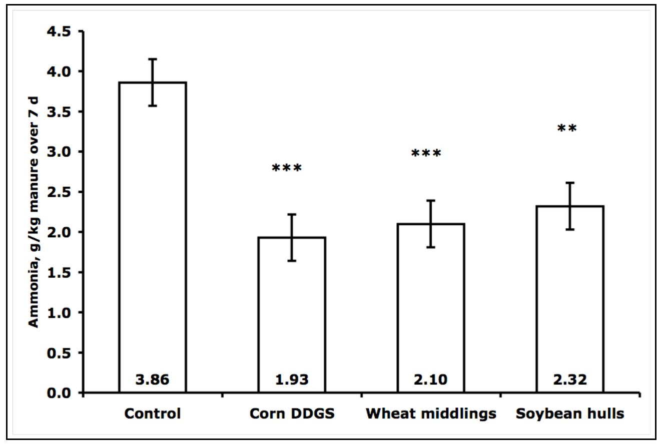

Figure 1. Ammonia emission from manure over 7 days. Means ± pooled SEM, n = 6. ***Different from control ($P \leq 0.001$). **Different from control ($P < 0.01$).

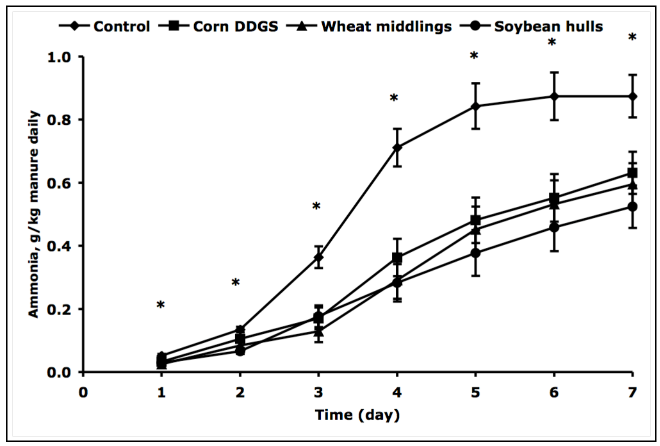

Figure 2. Ammonia-emission rate from manure over 7 days. Means ± pooled SEM, n = 6. *Control different from corn DDGS, wheat middlings, and soybean hulls ($P < 0.05$).

The pH of slurry is a major determinant of the rate and extent of ammonia volatilization from animal waste. In the present study, the pH of the manure from hens fed corn DDGS or wheat middlings was lower ($P < 0.05$), whereas the manure from soybean hulls-fed hens tended ($P = 0.06$) to have a lower pH compared to manure from hens fed the control diet (Table 2). Because the manure nitrogen was apparently not repartitioned from uric acid to bacterial protein, the lower pH was probably responsible for the lower ammonia emission that was observed from the manure of the fiber-fed hens. The lower pH may stem from an increased production of short-chain fatty acids caused by the increased bacterial fermentation of dietary fiber. Indeed, higher contents of short-chain fatty acids were observed in the manure from hens fed each of the three high-fiber diets compared to manure from the control-fed hens (data not shown).

The addition of dietary fiber did not affect ($P < 0.05$) egg production or egg mass (Table 2). Although diets were formulated to be isoenergetic, hens fed the corn DDGS or soybean hulls diets consumed more feed ($P < 0.05$) compared to hens fed the control diet (Table 2). Although the diets were formulated to be isoenergetic, energy contents for the fiber ingredients were obtained from National Research Council (**NRC**) tables, which may have stated values higher than the actual energy contents of the ingredients, causing the diets with the high-fiber ingredients to have a lower energy content than the control diets. The hens fed the corn DDGS or soybean hulls diets may have consumed more feed in order to consume enough energy to meet requirements. Nevertheless, feed utilization was not affected ($P > 0.10$) by the fiber addition (Table 2).

Egg yolk color was measured using the L*, a*, b* color system. The L* value indicates dark to light, a* indicates green to red, and b* indicates blue to yellow. Because corn contains high amounts of xanthophylls, which are a primary contributor of yolk pigmentation, corn DDGS was expected to affect egg-yolk color. Indeed, L* values were lower ($P < 0.05$), indicating a darker color, and a* values were higher ($P < 0.05$), indicating a redder color of the egg yolks compared to yolks of eggs from hens fed the control diet (Table 2). The wheat middlings or soybean hulls did not affect ($P > 0.10$) egg yolk color (Table 2). There were no effects ($P > 0.10$) of the corn DDGS, wheat middlings, or soybean hulls treatments on egg composition (Table 2).

Nitrogen balance and nitrogen and dry matter digestibility values are shown in Table 2. Nitrogen consumption was higher ($P \leq 0.05$) for hens fed corn DDGS, wheat middlings, or soybean hulls compared to hens fed the control diet. This was expected because the amino acids in the diets that include high-fiber feed ingredients are typically less digestible compared to the amino acids in the control diet, causing diets formulated to contain equal contents of true digestible amino acids to have higher crude protein contents when high-fiber ingredients are included, and thus higher total nitrogen contents. The higher nitrogen consumption of hens fed each of the three fiber diets was expected to result in a higher nitrogen excretion, however, nitrogen excretion was unaffected ($P > 0.05$) and, as a result, nitrogen retention was higher ($P \leq 0.01$) for the hens fed corn DDGS or wheat middlings compared to hens fed the control diet. This effect was likely due to table values for true ileal digestible amino acid contents of the high-fiber feed ingredients being lower than the actual contents of true ileal digestible amino acids in the ingredients, and as a result, hens fed the high-fiber diets consumed more digestible amino acids than was anticipated based on diet formulation. The apparent fecal nitrogen and dry matter digestibilities were calculated for the diets in the present study because addition of high-fiber feed ingredients has been shown to lower digestibility. However, the apparent fecal nitrogen digestibility was greater ($P < 0.05$) for the wheat middlings diet compared to the control diet and the corn DDGS and soybean hulls had a numerically but not statistically greater nitrogen digestibility. The immobilized digestive enzyme assay (**IDEA**; Novus International, St. Louis, MO) was performed on the corn DDGS to measure the amino acid digestibilities. This assay showed that the table values for digestibility coefficients used to formulate the diets were lower than the actual contents of digestible amino acids. The higher contents of digestible amino acids could partially account for the increased nitrogen digestibility observed when a decreased or equal nitrogen digestibility was expected between the high-fiber diets and the control diet. The apparent fecal dry matter digestibility was not different ($P > 0.05$) for the corn DDGS, wheat middlings, or soybean hulls diets compared to the control diet (Table 2). Hens fed the corn DDGS, wheat middlings or soybean hulls diets did not ($P > 0.05$) excrete more manure on a dry matter basis compared to hens fed the control diet (data not shown), which agrees with the calculated dry matter digestibility that was not different between the high-fiber diets and the control diet.

Conclusions

Results of this study show that addition of 10% corn DDGS, 7% wheat middlings, or 5% soybean hulls to laying-hen diets results in up to 50% lower manure ammonia emission and ammonia-emission rate. This effect was apparently caused by a lower pH of the manure and not by a repartitioning of nitrogen excretion to bacterial protein. Egg production and egg mass were not adversely affected by the addition of dietary fiber, although feed consumption was increased slightly (by 2%) for the hens fed the corn DDGS or soybean hulls diets. Nitrogen digestibility was unexpectedly increased by the wheat middlings diet, but dry matter digestibility was unaffected by the high-fiber diets.

Acknowledgements

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Table 1. Diet composition and calculated chemical analysis

Item	Control	Corn DDGS[1]	Wheat Middlings	Soybean Hulls
Ingredient (% of diet)				
Corn DDGS[1]	—	10.00	—	—
Wheat middlings	—	—	7.30	—
Soybean hulls	—	—	—	4.80
Corn	62.82	51.90	54.92	56.55
Soybean meal	18.52	18.37	17.62	18.43
Limestone	8.96	9.00	8.98	8.90
Meat and bone meal	5.00	5.00	5.00	5.00
Vegetable fat	2.27	3.65	3.85	3.88
Celite[2]	1.00	1.00	1.00	1.00
Dicalcium phosphate	0.27	0.14	0.21	0.28
Sodium bicarbonate	0.20	—	0.11	0.12
Trace-mineral premix[3]	0.30	0.30	0.30	0.30
Vitamin Premix[4]	0.30	0.30	0.30	0.30
Salt (iodized)	0.19	0.21	0.24	0.25
Alimet	0.17	0.13	0.17	0.19
Total	100.00	100.00	100.00	100.00
Calculated chemical composition				
Crude protein, %	16.94	18.37	17.05	16.77
ME_n[6], kcal/kg	2840	2840	2840	2840
Ether extract, %	4.72	6.07	6.25	6.15
Linoleic acid, %	1.47	1.69	1.43	1.34
Neutral-detergent fiber, %	12.58	14.55	14.80	15.11
Acid-detergent fiber, %	3.04	3.89	3.55	5.04
Crude fiber, %	1.61	2.06	2.14	3.41
Calcium, %	4.00	4.00	4.00	4.00
Phosphorus (non-phytate), %	0.37	0.37	0.37	0.37
Potassium, %	0.64	0.67	0.67	0.68
Sodium, %	0.18	0.18	0.18	0.18
Chloride, %	0.19	0.21	0.21	0.22
Dietary electrolyte balance, mEq[5]	191	191	191	191
Isoleucine (digestible), %	0.60	0.64	0.60	0.59
Lysine (digestible), %	0.73	0.73	0.73	0.73
Methionine (digestible), %	0.39	0.38	0.39	0.40
TSAA[7] (digestible), %	0.61	0.61	0.61	0.61
Threonine (digestible), %	0.54	0.56	0.53	0.53
Tryptophan (digestible), %	0.18	0.19	0.18	0.18
Valine (digestible), %	0.70	0.75	0.70	0.69

[1]DDGS = distiller's dried grains with solubles.

[2]Celite included as an indigestible marker.

[3]Supplied per kilogram of diet: manganese, 70 mg; zinc, 90 mg; iron (ferrous sulfate), 60 mg; copper, 12 mg; selenium (sodium selenite), 0.15 mg; sodium chloride, 2.5 g.

[4]Supplied per kilogram of diet: vitamin A (retinyl acetate), 8,065 IU; cholecalciferol, 1,580 IU; vitamin E (DL-α-tocopheryl acetate), 15 IU; vitamin B_{12}, 16 µg; vitamin K (menadione sodium bisulfite), 4 mg; riboflavin, 7.8 mg; pantothenic acid, 12.8 mg; niacin, 75 mg; choline, 509 mg; folic acid 1.62 mg; biotin, 270 µg.

[5]Dietary electrolyte balance calculated as K + Na – Cl.

[6]ME_n = nitrogen-corrected metabolizable energy.

[7]TSAA = total sulfur amino acids (methionine and cysteine).

Table 2. Specific endpoints measured for hens fed either a control diet or diets containing corn distiller's dried grains with solubles, wheat middlings, or soybean hulls.

Item	Control	Corn DDGS[1]	Wheat Middlings	Soybean Hulls	Pooled SEM
Uric acid N, % of total N	71.16	65.10	67.78	69.32	2.63
pH	7.08	6.77**	6.80*	6.85†	0.04
Egg production, %	89.1	89.7	89.3	87.8	0.8
Egg weight, g/egg	60.7	61.4	61.7	62.2*	0.5
Egg mass, g/hen	54.1	54.9	55.0	54.6	0.4
Feed consumption, g/hen	97.8	99.7*	99.3	99.8*	0.7
Feed utilization[2]	556	553	556	548	5
Egg yolk color[3]					
L*	80.67	80.11*	80.69	80.69	0.18
a*	5.27	6.62***	5.25	5.26	0.25
b*	86.72	87.13	86.82	86.56	0.40
Egg composition					
Solids[4]	21.21	20.96	21.40	21.22	0.13
Yolk	28.25	27.97	28.41	28.20	0.20
Albumen	58.89	59.42	58.87	59.12	0.24
Shell	12.86	12.61	12.72	12.68	0.13
Nitrogen balance					
Nitrogen intake, g/d	2.33	2.64***	2.50***	2.41*	0.02
Nitrogen in egg, g/d	0.92	0.91	0.90	0.90	0.03
Nitrogen excretion, g/d	1.61	1.68	1.49	1.54	0.07
Nitrogen retention, g/d	–0.18	0.08**	0.10**	–0.02	0.07
Nitrogen digestibility, %	31.14	36.20	40.23*	36.16	2.73
Dry matter digestibility, %	63.50	62.41	64.88	63.36	1.14

†$P < 0.10$, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, P-value for the contrast of control vs. corn DDGS, wheat middlings, or soybean hulls, n = 32.

[1]DDGS = distiller's dried grains with solubles.

[2]Gram egg mass:kilogram feed.

[3]Hunter Lab values: L* = black and white, a* = red and green, b* = yellow and blue.

[4]Egg solids calculated as dry weight of yolk and albumen divided by whole egg weight.