Effects of Dietary Fiber and Reduced Crude Protein on Nitrogen Balance and Egg Production in Laying Hens

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Abstract
Ammonia emission is a major concern for the poultry industry and can be lowered by dietary inclusion of fibrous ingredients and by lowering the dietary CP content. The objectives of this research were to determine the effects of dietary fiber and reduced-CP diets, which may lower NH3 emission, on egg production and N balance in laying hens. A total of 256 Hy-Line W-36 hens were fed diets with 2 contents of CP (normal and reduced) and 4 fiber treatments in a 2 × 4 factorial arrangement from 23 to 58 wk of age. The fiber treatments included a corn and soybean meal-based control diet and diets formulated with either 10.0% corn dried distillers grains with solubles (DDGS), 7.3% wheat middlings (WM), or 4.8% soybean hulls (SH) added to contribute equal amounts of neutral detergent fiber. The CP contents of the reduced-CP diets were approximately 1 percentage unit lower than that of the normal-CP diets. All diets were formulated on a digestible amino acid basis to be isoenergetic. There were no effects ($P > 0.05$) of including corn DDGS, WM, or SH in the diet on egg production, egg weight, egg mass, yolk color, feed consumption, feed utilization, or BW gain. Although the corn DDGS and WM diets resulted in an increase ($P < 0.001$) in N consumption, N excretion was not affected ($P > 0.10$) compared with hens fed the control diet. The reduced-CP diets did not affect egg weight, feed consumption, or BW gain ($P > 0.05$); however, egg production, egg mass, feed utilization, N consumption, and N excretion were lower than that from the hens fed the normal-CP diets ($P < 0.05$). The results of this study show that the diets containing 10% corn DDGS, 7% WM, or 5% SH did not affect egg production or N excretion. However, the 1% lower CP diets caused a lower egg production and lower N excretion.

Keywords
corn-dried distillers grains with solubles, egg production, reduced crude protein diet, soybean hull, wheat middlings

Disciplines
Agriculture | Animal Sciences | Bioresource and Agricultural Engineering | Poultry or Avian Science

Comments
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Effects of Dietary Fiber and Reduced Crude Protein on Nitrogen Balance and Egg Production in Laying Hens[1]

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ABSTRACT Ammonia emission is a major concern for the poultry industry and can be lowered by dietary inclusion of fibrous ingredients and by lowering the dietary CP content. The objectives of this research were to determine the effects of dietary fiber and reduced-CP diets, which may lower NH_3 emission, on egg production and N balance in laying hens. A total of 256 Hy-Line W-36 hens were fed diets with 2 contents of CP (normal and reduced) and 4 fiber treatments in a 2 × 4 factorial arrangement from 23 to 58 wk of age. The fiber treatments included a corn and soybean meal-based control diet and diets formulated with either 10.0% corn dried distillers grains with solubles (DDGS), 7.3% wheat middlings (WM), or 4.8% soybean hulls (SH) added to contribute equal amounts of neutral detergent fiber. The CP contents of the reduced-CP diets were approximately 1 percentage unit lower than that of the normal-CP diets. All diets were formulated on a digestible amino acid basis to be isoenergetic. There were no effects ($P > 0.05$) of including corn DDGS, WM, or SH in the diet on egg production, egg weight, egg mass, yolk color, feed consumption, feed utilization, or BW gain. Although the corn DDGS and WM diets resulted in an increase ($P < 0.001$) in N consumption, N excretion was not affected ($P > 0.10$) compared with hens fed the control diet. The reduced-CP diets did not affect egg weight, feed consumption, or BW gain ($P > 0.05$); however, egg production, egg mass, feed utilization, N consumption, and N excretion were lower than that from the hens fed the normal-CP diets ($P < 0.05$). The results of this study show that the diets containing 10% corn DDGS, 7% WM, or 5% SH did not affect egg production or N excretion. However, the 1% lower CP diets caused a lower egg production and lower N excretion.

Key words: corn-dried distillers grains with solubles, egg production, reduced crude protein diet, soybean hull, wheat middlings

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INTRODUCTION

Excretion of N, part of which is volatilized as NH_3 and lost to the atmosphere, is a concern to the poultry industry. In the United States, poultry (including laying hens) is the largest contributor of atmospheric NH_3 emissions among domestic animal species, accounting for 27% of the total NH_3 emissions in 2002 based on national emission inventory estimation (EPA, 2004; Aneja et al., 2006). Not only can NH_3 adversely affect health and production of poultry by contributing to deciliation of the trachea, corneal ulcers, impairment of macrophage function, reduced lung function, lower egg production, and lower BW gains (Kling and Quarles, 1974; Nagaraja et al., 1983; Carlile, 1984; Deaton et al., 1984; Omland, 2002; Miles et al., 2004), but it may also cause eutrophication of surface water resources and nuisance odors (De Boer et al., 2000; Angus et al., 2003; Ritz et al., 2004). The Federal Comprehensive Environmental Response, Compensation, and Liability Act and Emergency Planning and Community Right to Know Act require reporting of releases of NH_3 above 45 kg per day per animal-housing site, and the United Egg Producers animal husbandry guidelines (United Egg Producers, 2006) recommend atmospheric NH_3 concentrations below 25 ppm in laying-hen houses. Inclusion of feed ingredients with high concentrations of fiber has been shown to lower NH_3 emission from pigs and laying hens (Kreuzer and Machmuller, 1993; Tetens et al., 1996; Canh et al., 1997; Shriver et al., 2003; Roberts et al., 2007), and reduced-CP diets have been shown to decrease N excretion and NH_3 emission from pigs, broilers, and laying hens (Summers, 1993; Summers and Leeson, 1994; Bregendahl et al., 2002; Keshavarz and Austic, 2004). High-fiber or reduced-CP diets have been fed to laying hens without causing a depression in egg production (Summers, 1993; Leeson and Caston, 1996; Jaroni et

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[1]Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by Iowa State University or the USDA and does not imply approval to the exclusion of other products that may be suitable.
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Table 1. Analyzed chemical composition of feed ingredients (as-is basis)[1]

Item	Corn	Soybean meal	Meat and bone meal	Corn DDGS	Wheat middlings	Soybean hulls
	%					
Moisture	13.39	10.94	3.38	9.20	13.66	8.82
CP	8.67	48.01	52.01	24.51	16.87	8.73
Ether extract	2.94	0.74	10.27	3.13	2.99	0.79
Neutral detergent fiber	11.87	14.07	49.87	32.90	45.04	68.54
Crude fiber	1.52	3.31	0.94	6.19	9.29	39.39
Amino acids (total)						
Ile	0.31	2.19	1.27	0.82	0.56	0.31
Lys	0.26	2.99	2.70	0.48	0.76	0.60
Met	0.17	0.69	0.76	0.41	0.28	0.11
TSAA	0.35	1.41	1.20	0.89	0.62	0.27
Thr	0.29	1.88	1.70	0.84	0.58	0.32
Trp	0.08	0.79	0.37	0.17	0.18	0.09
Val	0.41	2.30	1.90	1.14	0.86	0.44

[1]Values are the result of one measurement for each analysis except neutral detergent fiber, which is the mean of 3 observations per ingredient. DDGS = dried distillers grains with solubles.

al., 1999a; Lumpkins et al., 2005). However, the inclusion of high-fiber feed ingredients in diets fed to pigs or poultry may lower nutrient digestibility and, therefore, increase total N excretion (Jaroni et al., 1999b; Dilger et al., 2004; Hogberg and Lindberg, 2004). We hypothesized that including high-fiber feed ingredients and reducing the CP contents of laying-hen diets would contribute to a decrease in NH_3 emission from manure with no adverse effects on egg production or N balance. In a separate report, we showed that dietary inclusion of 10% corn dried distillers grains with solubles (**DDGS**), 7.3% wheat middlings (**WM**), or 4.8% soybean hulls (**SH**) lowered ($P < 0.05$) the NH_3 emission from laying-hen manure by up to 50% as a result of lowering the manure pH, but reducing the CP content by 1 percentage unit did not elicit a significant change in NH_3 emission (Roberts et al., 2007). The objectives of this study were to determine the effects of dietary fiber and reduced-CP diets on egg production, feed consumption, N and DM digestibilities, and N balance in laying hens.

MATERIALS AND METHODS

Birds and Housing

A total of 256 Hy-Line W-36 laying hens were obtained from a commercial facility at 17 wk of age and placed in a completely enclosed fan-ventilated light- (12L:12D) and temperature- (20°C) controlled room. Hens were housed 2 per cage, corresponding to 619 cm^2 (96 in^2) per hen, in wire-bottomed cages (Chore-Time, Milford, IN) each equipped with a plastic self-feeder and a nipple drinker. Feeders were fitted with a wire grate to minimize waste of feed but not restrict feed consumption. Photoperiod was increased incrementally according to the *Hy-Line W-36 2003–2005 Commercial Management Guide* (Hy-Line International, Des Moines, IA) to 16L:8D at 25 wk of age. Prelay and prepeak diets were formulated according to recommendations in the W-36 commercial management guide for 17 to 18 and 19 to 22 wk of age, respectively, and fed to all hens before the commencement of the trial. At 23 wk of age (corresponding to 95% production), hens were reassigned to cages according to a randomized complete block design with BW and cage location within the barn as blocking criteria, and hens were fed the treatment diets. The Iowa State University Institutional Animal Care and Use Committee approved techniques and procedures involved in the animal care and handling.

Experimental Diets

Before formulation of diets, all protein-supplying ingredients were analyzed for contents of total amino acids by methods 982.30E a, b, and c (AOAC, 2006) and for CP by method 990.03 (AOAC, 2006), ether extract by method 920.39A (AOAC, 2006), and crude fiber by method 978.10 (AOAC, 2006) at the Missouri Experiment Station Chemical Laboratories (University of Missouri, Columbia; Table 1). Ingredients were also analyzed for neutral detergent fiber by the method of Van Soest and Robertson (1979) using an Ankom fiber analyzer (Ankom Technology Corporation, Fairport, NY). The analyzed total amino acid contents were adjusted to true digestible amino acid contents using coefficients published by Ajinomoto Heartland (2005). The requirements for true digestible amino acids of the hens were estimated as 89% (i.e., the average true digestibility coefficient of the amino acids in corn and soybean meal) of the recommendations for total amino acids, which were derived from NRC (1994) and recent literature (Harms and Russell, 1996, 2000a,b; Russell and Harms, 1999; Faria et al., 2002; Antar et al., 2004). Target values for daily consumption of true digestible amino acids were as follows: 580 mg of Ile, 765 mg of Lys, 340 mg of Met, 640 mg of TSAA, 445 mg of Thr, 135 mg of Trp, and 625 mg of Val for hens 32 to 44 wk of age. Hens were phase-fed to account for changes in nutrient requirements and feed consumption with age: phase 1 (23 to 31 wk of age), phase 2 (32 to 44 wk of age), and phase 3 (45 to 58 wk of age) were formulated with 105, 100, and 95 of the amino acid target values, respectively.

Table 2. Phase 1 (23 to 31 wk of age) diet composition and calculated chemical analyses[1]

Item	Normal CP				Reduced CP			
	Control	Corn DDGS	WM	SH	Control	Corn DDGS	WM	SH
	%							
Ingredient								
Corn DDGS	—	10.00	—	—	—	10.00	—	—
WM	—	—	7.30	—	—	—	7.30	—
SH	—	—	—	4.80	—	—	—	4.80
Corn	49.73	38.83	42.00	43.52	51.85	43.20	43.60	45.11
Soybean meal (48% CP)	26.78	26.62	25.76	26.63	24.90	22.76	24.35	25.24
Calcium carbonate	9.59	9.63	9.61	9.52	9.59	9.61	9.60	9.52
Meat and bone meal (50% CP)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Vegetable oil	5.85	7.22	7.39	7.46	5.49	6.49	7.12	7.17
Dicalcium phosphate	1.00	0.87	0.93	1.02	1.01	0.90	0.95	1.03
Celite[2]	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Sodium bicarbonate	0.20	—	0.11	0.13	0.30	0.19	0.18	0.20
Trace mineral premix[3]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix[4]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Sodium chloride (iodized)	0.26	0.28	0.31	0.31	0.19	0.15	0.26	0.27
Alimet	0.29	0.25	0.29	0.31	0.31	0.29	0.30	0.32
L-Lys·HCl	—	—	—	—	0.06	0.11	0.04	0.04
Calculated chemical composition								
CP	19.77	21.19	19.84	19.58	19.10	19.82	19.34	19.08
ME_n, kcal/kg	2,900	2,900	2,900	2,900	2,900	2,900	2,900	2,900
Ether extract	7.91	9.24	9.40	9.34	7.60	8.63	9.17	9.09
Linoleic acid	1.22	1.43	1.18	1.08	1.26	1.51	1.21	1.11
Neutral detergent fiber	12.19	14.16	14.41	14.72	12.18	14.13	14.40	14.71
Acid detergent fiber	3.12	3.96	3.63	5.12	3.08	3.88	3.60	5.09
Crude fiber	1.69	2.14	2.22	3.48	1.66	2.08	2.19	3.46
Ca	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
P (nonphytate)	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
K	0.77	0.80	0.80	0.80	0.74	0.73	0.77	0.78
Na	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Cl	0.23	0.25	0.26	0.25	0.20	0.20	0.23	0.24
Dietary electrolyte balance,[5] mEq	223	223	223	223	223	223	223	223
Ile (digestible)	0.73	0.76	0.72	0.72	0.70	0.70	0.70	0.70
Lys (digestible)	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
TSAA (digestible)	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Thr (digestible)	0.64	0.67	0.64	0.63	0.61	0.61	0.62	0.61
Trp (digestible)	0.23	0.24	0.23	0.23	0.22	0.22	0.22	0.22
Val (digestible)	0.82	0.87	0.82	0.81	0.79	0.80	0.80	0.79

[1]DDGS = dried distillers grains with solubles; WM = wheat middlings; SH = soybean hulls.

[2]Celite was included as an indigestible marker (Celite Corp., Lompoc, CA).

[3]Supplied the following per kilogram of diet: Mn ($MnSO_4$), 70 mg; Zn (ZnO), 90 mg; Fe ($FeSO_4$), 60 mg; Cu ($CuSO_4$), 12 mg; Se (Na_2SeO_3), 0.15 mg; and NaCl, 2.5 g.

[4]Supplied the following 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; and biotin, 270 μg.

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

Diets were formulated for total Ca, nonphytate P, and ME contents according to recommendations in the W-36 commercial management guide; $NaHCO_3$ (American Soda, Parachute, CO) was included to equalize the calculated dietary electrolyte balance among diets within a phase. All diets contained Celite (Celite Corporation, Lompoc, CA) as a source of acid insoluble ash (**AIA**), used as an indigestible marker.

A 2 × 4 factorial arrangement of treatments was used, with 2 contents of CP (normal and reduced) and 4 fiber diets (Tables 2, 3, and 4). The normal-CP diets were formulated to resemble diets typically used in industry, with meat and bone meal, corn, and soybean meal included to meet the digestible Lys target values. Methionine hydroxy analog (Alimet) was supplemented to meet the digestible TSAA target values. In the reduced-CP diets, the ratio of corn to soybean meal was adjusted so that the combination of corn, soybean meal, and meat and bone meal met the third and fourth limiting amino acid (i.e., Ile and Val) target values. Alimet and L-Lys·HCl were included in the formulation to meet the remainder of the digestible TSAA and Lys target values, respectively. The 4 fiber diets included a corn-soybean meal-based control diet, with the higher-fiber diets formulated to contain 10.0% corn DDGS, 7.3% WM, or 4.8% SH. Corn DDGS, WM, and SH were chosen for their high neutral detergent fiber content and availability in the Midwest. Although corn DDGS has been included in laying-hen diets at a rate of up to 15% with no adverse effects on egg production (Lumpkins et al., 2005), 10% inclusion was chosen in this study to more closely match the inclusion of corn DDGS in laying-hen diets in industry. The WM and SH were included in

Table 3. Phase 2 (32 to 44 wk of age) diet composition and calculated chemical analyses[1]

	Normal CP				Reduced CP			
Item	Control	Corn DDGS	WM	SH	Control	Corn DDGS	WM	SH
	%							
Ingredient								
Corn DDGS	—	10.00	—	—	—	10.00	—	—
WM	—	—	7.30	—	—	—	7.30	—
SH	—	—	—	4.80	—	—	—	4.80
Corn	58.08	47.25	50.34	51.78	61.27	52.44	52.88	54.31
Soybean meal (48% CP)	21.80	21.60	20.80	21.75	18.95	16.97	18.56	19.54
Calcium carbonate	8.76	8.79	8.78	8.69	8.74	8.77	8.77	8.68
Meat and bone meal (50% CP)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Vegetable oil	3.50	4.85	5.04	5.11	2.97	3.99	4.61	4.68
Celite[2]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Dicalcium phosphate	0.62	0.49	0.55	0.64	0.65	0.53	0.57	0.66
Trace mineral premix[3]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix[4]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Sodium bicarbonate	0.20	—	0.11	0.12	0.35	0.24	0.22	0.24
Sodium chloride (iodized)	0.22	0.24	0.26	0.28	0.13	0.09	0.18	0.19
Alimet	0.22	0.18	0.22	0.23	0.25	0.22	0.24	0.25
L-Lys·HCl	—	—	—	—	0.09	0.15	0.07	0.07
Calculated chemical composition								
CP	18.10	19.52	18.18	17.95	17.09	17.88	17.39	17.17
ME_n, kcal/kg	2,862	2,862	2,862	2,862	2,862	2,862	2,862	2,862
Ether extract	5.81	7.13	7.31	7.24	5.37	6.41	6.94	6.88
Linoleic acid	1.38	1.60	1.35	1.24	1.44	1.69	1.39	1.29
Neutral detergent fiber	12.48	14.45	14.70	15.01	12.46	14.42	14.69	15.00
Acid detergent fiber	3.08	3.93	3.59	5.09	3.02	3.82	3.54	5.04
Crude fiber	1.65	2.10	2.18	3.45	1.61	2.02	2.14	3.41
Ca	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
P (nonphytate)	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
K	0.69	0.72	0.72	0.73	0.64	0.64	0.68	0.69
Na	0.19	0.19	0.19	0.19	0.20	0.20	0.19	0.19
Cl	0.20	0.23	0.23	0.24	0.17	0.17	0.19	0.20
Dietary electrolyte balance,[5] mEq	204	204	204	204	204	204	204	204
Ile (digestible)	0.66	0.69	0.65	0.65	0.61	0.61	0.61	0.61
Lys (digestible)	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
TSAA (digestible)	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Thr (digestible)	0.58	0.61	0.57	0.57	0.54	0.54	0.54	0.54
Trp (digestible)	0.20	0.21	0.20	0.20	0.18	0.18	0.19	0.19
Val (digestible)	0.75	0.80	0.75	0.74	0.70	0.72	0.71	0.70

[1]DDGS = dried distillers grains with solubles; WM = wheat middlings; SH = soybean hulls.

[2]Celite was included as an indigestible marker (Celite Corp., Lompoc, CA).

[3]Supplied the following per kilogram of diet: Mn ($MnSO_4$), 70 mg; Zn (ZnO), 90 mg; Fe ($FeSO_4$), 60 mg; Cu ($CuSO_4$), 12 mg; Se (Na_2SeO_3), 0.15 mg; and NaCl, 2.5 g.

[4]Supplied the following 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; and biotin, 270 μg.

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

the respective diets to supply equal amounts of neutral detergent fiber as that of the 10% corn DDGS. The diets were analyzed as previously described for the feed ingredients; Novus International (St. Louis, MO) analyzed the Alimet contents in the diets (Table 5).

Collection and Analyses

Production. Egg production was recorded daily. Eggs were collected for a 24-h period each week for measurement of egg weight and calculation of egg mass (egg production × egg weight). During wk 4 of each phase, eggs collected for egg weight were used for determination of egg composition. Each egg was broken and the weight of the yolk, shell, and albumen recorded separately. If the combined wet weight of the yolk, shell, and albumen of the egg was less than 95% of the whole egg weight, observations from that egg were removed. Egg solids (%) were measured by drying the albumen and yolk at 70°C for 24 h and calculated as the combined weight of the dry albumen and yolk divided by the wet weight of the whole egg. Eggs from an additional 24-h period during wk 4 of each phase were saved for measurement of yolk color using a Minolta Chroma Meter CR-310 (Minolta Corporation, Ramsey, NJ) calibrated with a white calibration plate. The Chroma Meter measures Hunter L*, a*, and b* values, where L* is a measure of dark to light, with a greater value indicating a lighter color; a* is a measure of green to red, with a greater value indicating a redder color; and b* is a measure of blue to yellow, with a greater value indicating a more yellow color. The yolk from each egg was placed in a petri dish, and the

Table 4. Phase 3 (45 to 58 wk of age) diet composition and calculated chemical analyses[1]

Item	Normal CP				Reduced CP			
	Control	Corn DDGS	WM	SH	Control	Corn DDGS	WM	SH
	%							
Ingredient								
Corn DDGS	—	10.00	—	—	—	10.00	—	—
WM	—	—	7.30	—	—	—	7.30	—
SH	—	—	—	4.80	—	—	—	4.80
Corn	62.82	51.90	54.92	56.55	66.40	57.28	57.78	59.21
Soybean meal (48% CP)	18.52	18.37	17.62	18.43	15.27	13.50	15.09	16.04
Calcium carbonate	8.96	9.00	8.98	8.90	8.95	8.97	8.97	8.88
Meat and bone meal (50% CP)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Vegetable oil	2.27	3.65	3.85	3.88	1.69	2.78	3.37	3.44
Celite[2]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Dicalcium phosphate	0.27	0.14	0.21	0.28	0.30	0.19	0.23	0.33
Sodium bicarbonate	0.20	—	0.11	0.12	0.37	0.25	0.24	0.25
Trace mineral premix[3]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix[4]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Sodium chloride (iodized)	0.19	0.21	0.24	0.25	0.11	0.10	0.15	0.16
Alimet	0.17	0.13	0.17	0.19	0.20	0.18	0.19	0.21
L-Lys·HCl	—	—	—	—	0.11	0.15	0.08	0.08
Calculated chemical composition								
CP	16.94	18.37	17.05	16.77	15.79	16.64	16.16	15.92
ME_n, kcal/kg	2,840	2,840	2,840	2,840	2,840	2,840	2,840	2,840
Ether extract	4.72	6.07	6.25	6.15	4.24	5.33	5.85	5.78
Linoleic acid	1.47	1.69	1.43	1.34	1.54	1.79	1.49	1.39
Neutral detergent fiber	12.58	14.55	14.80	15.11	12.55	14.51	14.78	15.09
Acid detergent fiber	3.04	3.89	3.55	5.04	2.96	3.77	3.49	4.99
Crude fiber	1.61	2.06	2.14	3.41	1.56	1.98	2.10	3.37
Ca	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
P (nonphytate)	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
K	0.64	0.67	0.67	0.68	0.59	0.59	0.63	0.64
Na	0.18	0.18	0.18	0.18	0.20	0.21	0.18	0.18
Cl	0.19	0.21	0.21	0.22	0.16	0.18	0.18	0.18
Dietary electrolyte balance,[5] mEq	191	191	191	191	191	191	191	191
Ile (digestible)	0.60	0.64	0.60	0.59	0.55	0.55	0.55	0.55
Lys (digestible)	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
TSAA (digestible)	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Thr (digestible)	0.54	0.56	0.53	0.53	0.49	0.50	0.50	0.50
Trp (digestible)	0.18	0.19	0.18	0.18	0.16	0.16	0.17	0.17
Val (digestible)	0.70	0.75	0.70	0.69	0.65	0.67	0.66	0.65

[1]DDGS = dried distillers grains with solubles; WM = wheat middlings; SH = soybean hulls.

[2]Celite was included as an indigestible marker (Celite Corp., Lompoc, CA).

[3]Supplied the following per kilogram of diet: Mn ($MnSO_4$), 70 mg; Zn (ZnO), 90 mg; Fe ($FeSO_4$), 60 mg; Cu ($CuSO_4$), 12 mg; Se (Na_2SeO_3), 0.15 mg; and NaCl, 2.5 g.

[4]Supplied the following 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; and biotin, 270 μg.

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

contents were spread evenly into a circle with a similar diameter as the light-projection tube on the color meter.

Hen BW was measured at the beginning of the experiment and after each phase. Feed consumption was recorded weekly and calculated as grams of feed disappearance over 7 d divided by the number of hen days, adjusted for mortalities (only 4 hens died during the study, of causes not attributed to the dietary treatments). Feed utilization was calculated weekly as grams of egg mass divided by kilograms of feed consumed.

N Balance. Nitrogen balance was determined during wk 6 of phase 3 (birds at 51 wk of age). Manure was collected from each cage within 2 min of excretion over 4 h, placed into capped 50-mL centrifuge tubes, and stored on ice. Manure was analyzed for N contents using micro-Kjeldahl method 984.13 (AOAC, 2006) on a Kjeltech 1028 distilling unit (US Tecator Inc., Herndon, VA) on the day of collection, and the remaining sample was stored at –20°C until further analysis. Manure was thawed, dried, and analyzed for contents of AIA using the method of Vogtmann et al. (1975). Details of the manure collection and analyses are described by Roberts et al. (2007). Eggs from a 48-h collection period, during the same week as manure collection, were used for determination of egg N. Eggs were weighed, broken, and the albumen and yolk pooled within cage. The yolk-albumen mixture was weighed, 4 mL was removed for DM determination by drying at 70°C for 24 h, and the remainder frozen at –20°C. The frozen egg contents were lyophilized and subsequently analyzed for N content.

The following calculations were used to determine manure excretion, N excretion, N retention, apparent fecal

Table 5. Diet analyzed chemical composition[1]

	Normal CP				Reduced CP			
Item	Control	Corn DDGS	WM	SH	Control	Corn DDGS	WM	SH
	%							
Phase 1								
CP	21.90	23.07	21.62	21.14	20.16	20.93	20.84	20.76
Ether extract	8.36	9.13	9.39	8.79	8.32	8.98	9.63	9.64
Neutral detergent fiber	8.20	10.43	10.75	11.44	7.55	10.74	10.55	11.08
Acid detergent fiber	4.07	5.01	5.08	6.46	4.06	5.19	5.00	6.58
Crude fiber	1.48	1.87	1.88	3.24	1.30	1.86	1.87	3.16
Ile (total)	0.97	0.92	0.88	0.87	0.80	0.80	0.83	0.86
Lys (total)	1.22	1.13	1.12	1.13	1.09	1.09	1.09	1.14
Met[2] (total)	0.59	0.53	0.48	0.54	0.51	0.53	0.48	0.53
TSAA[2] (total)	0.91	0.87	0.79	0.84	0.80	0.83	0.78	0.82
Thr (total)	0.82	0.86	0.79	0.78	0.74	0.80	0.76	0.75
Trp (total)	0.28	0.25	0.23	0.23	0.24	0.21	0.22	0.22
Val (total)	1.13	1.09	1.02	1.03	0.95	0.96	0.98	0.95
Phase 2								
CP	18.65	20.16	19.62	19.04	18.27	19.01	18.37	18.57
Ether extract	6.37	7.04	6.77	6.41	5.26	6.03	6.69	6.23
Neutral detergent fiber	8.01	10.61	11.01	11.56	8.71	10.63	10.63	11.82
Acid detergent fiber	3.95	3.07	3.88	6.45	2.19	2.95	2.68	4.74
Crude fiber	1.24	1.60	1.83	2.74	1.29	1.71	1.70	3.07
Ile (total)	0.74	0.77	0.77	0.76	0.70	0.71	0.70	0.73
Met[2] (total)	0.46	0.44	0.44	0.48	0.45	0.47	0.42	0.48
TSAA[2] (total)	0.73	0.74	0.73	0.76	0.71	0.74	0.69	0.74
Lys (total)	0.95	0.95	0.98	0.99	1.06	0.99	0.97	1.03
Thr (total)	0.70	0.75	0.73	0.71	0.65	0.67	0.66	0.68
Trp (total)	0.22	0.22	0.21	0.21	0.20	0.19	0.20	0.19
Val (total)	0.89	0.94	0.92	0.88	0.84	0.86	0.85	0.87
Phase 3								
CP	17.60	19.06	18.00	17.70	16.53	17.06	15.80	16.50
Ether extract	4.67	5.70	5.89	5.68	3.98	4.72	4.75	3.29
Neutral detergent fiber	9.20	11.67	10.73	11.21	8.31	11.74	11.30	11.92
Acid detergent fiber	2.52	3.37	3.15	4.71	2.27	6.35	6.69	8.53
Crude fiber	1.83	2.52	2.53	3.76	1.91	2.22	2.21	3.22
Ile (total)	0.71	0.70	0.72	0.67	0.65	0.61	0.61	0.58
Met[2] (total)	0.41	0.40	0.39	0.41	0.38	0.42	0.36	0.36
TSAA[2] (total)	0.68	0.70	0.68	0.67	0.63	0.69	0.60	0.59
Lys (total)	0.88	0.89	0.91	0.86	0.89	0.88	0.85	0.82
Thr (total)	0.61	0.69	0.62	0.60	0.56	0.62	0.54	0.54
Trp (total)	0.19	0.21	0.20	0.18	0.16	0.17	0.17	0.17
Val (total)	0.83	0.85	0.86	0.80	0.78	0.74	0.75	0.70

[1]DDGS = dried distillers grains with solubles; WM = wheat middlings; SH = soybean hulls.

[2]Includes analyzed content of Alimet.

N digestibility, and apparent fecal DM digestibility. The excretion of DM manure was calculated as follows: $\text{Manure}_{\text{Excretion}} = (\text{AIA}_{\text{Feed}} \times \text{Feed}_{\text{Consumption}})/\text{AIA}_{\text{Manure}}$, where $\text{Manure}_{\text{Excretion}}$ = the manure excreted (g); AIA_{Feed} and $\text{AIA}_{\text{Manure}}$ = the analyzed AIA contents of feed and manure, respectively (%); and $\text{Feed}_{\text{Consumption}}$ = the feed consumed (g). Nitrogen excretion was calculated as follows: $\text{N}_{\text{Excretion}} = \text{Manure}_{\text{Excretion}} \times \text{N}_{\text{Manure}}$, where $\text{N}_{\text{Excretion}}$ = the N excreted (g) and N_{Manure} = the N content of the manure (%). The N retention was calculated as follows: $\text{N}_{\text{Retention}} = \text{N}_{\text{Consumption}} - \text{N}_{\text{Egg}} - \text{N}_{\text{Excretion}}$, where $\text{N}_{\text{Retention}}$ = the N retained by the hen (g); $\text{N}_{\text{Consumption}}$ = the N consumed (g); and N_{Egg} = the N in eggs (g). Apparent fecal N digestibility was calculated as follows: $\text{N}_{\text{Digestibility}} = 100 - [100 \times (\text{N}_{\text{Excretion}}/\text{N}_{\text{Consumption}})]$, where $\text{N}_{\text{Digestibility}}$ = the apparent fecal N digestibility of the N contents in the diet (%). The apparent fecal DM digestibility was calculated as follows: $\text{DM}_{\text{Digestibility}} = 100 - [100 \times (\text{Manure}_{\text{Excretion}}/\text{Feed}_{\text{Consumption}})]$, where $\text{DM}_{\text{Digestibility}}$ = the apparent fecal digestibility of the DM contents of the diet (%). All calculations were made on a DM basis, and results are expressed on a per-hen, per-day basis.

Statistical Analyses

Statistical analyses were performed using JMP (version 5.1.2, SAS Institute Inc., Cary, NC). Data were analyzed by ANOVA appropriate for a randomized complete block design with 16 blocks and 8 dietary treatments in a 2 × 4 factorial arrangement (Morris, 1999). The ANOVA model included effects of block, protein, fiber, and the interaction of protein and fiber. Dunnett's multiple comparison procedure (Dunnett, 1955) was used to compare the results from each of the fiber treatments to the results from the control; the main effect of protein was used to compare the reduced- and normal-CP diets. The experimental unit was a cage with 2 hens, and $P \leq 0.05$ was considered significant. There were no interactions ($P > 0.05$) between

Table 6. Egg production, feed consumption, feed efficiency, and BW gain[1]

	Fiber					Protein		
Item	Control	Corn DDGS	WM	SH	Pooled SEM	Normal	Reduced	Pooled SEM
Phase 1 (23 to 31 wk of age)								
Egg production, %	97.1	96.4	97.0	96.1	0.5	96.9	96.4	0.4
Egg weight, g/egg	55.0	55.3	55.7	55.5	0.3	55.4	55.3	0.2
Egg mass, g/d	53.4	53.3	54.1	53.4	0.4	53.7	53.4	0.3
Feed consumption, g/d	90.8	92.0	90.8	92.0	0.7	91.3	91.3	0.5
Feed utilization, g of egg mass:kg of feed	590	579	594	584	5	589	585	3
BW gain, g	123	122	117	116	7	123	116	5
Phase 2 (32 to 44 wk of age)								
Egg production, %	95.1	94.9	94.9	93.9	0.6	95.5[A]	94.0[B]	0.4
Egg weight, g/egg	58.6	59.4	59.7	59.6	0.4	59.5	59.2	0.3
Egg mass, g/d	55.8	56.4	56.6	56.0	0.4	56.8[B]	55.6[A]	0.3
Feed consumption, g/d	95.9	97.4	96.9	97.9	0.6	97.3	96.8	0.4
Feed utilization, g of egg mass:kg of feed	583	580	584	573	4	584[a]	576[b]	3
BW gain, g	68	52	76	74	7	71	64	5
Phase 3 (45 to 58 wk of age)								
Egg production, %	89.1	89.7	89.3	87.8	0.8	90.3[A]	87.6[B]	0.6
Egg weight, g/egg	60.7	61.4	61.7	62.2	0.5	61.6	61.4	0.3
Egg mass, g/d	54.1	54.9	55.0	54.6	0.4	55.6[A]	53.8[B]	0.3
Feed consumption, g/d	97.8	99.7	99.3	99.8	0.7	99.4	98.9	0.5
Feed utilization, g of egg mass:kg of feed	556	553	556	548	5	561[A]	546[B]	3
BW gain, g	67	51	69	47	9	60	57	6

[a,b]Means within a row lacking a common superscript differ ($P < 0.05$); n = 64.

[A,B]Means within a row lacking a common superscript differ ($P \leq 0.01$); n = 64.

[1]DDGS = dried distillers grains with solubles; WM = wheat middlings; SH = soybean hulls.

dietary fiber and CP contents, so the main effects of each factor are discussed separately.

RESULTS AND DISCUSSION

Adjusting diet composition may decrease the amount of NH_3 that is lost from laying-hen facilities but may also potentially affect egg production and N balance. Although the high-fiber ingredients resulted in a decrease in the total NH_3 emission and emission rate (Roberts et al., 2007), feeding high-fiber ingredients is only an acceptable method for egg producers to mitigate NH_3 emission if there are no adverse effects on egg production. In the present study, there were no effects ($P > 0.05$) of dietary inclusion of 10% corn DDGS, 7% WM, or 5% SH on egg production, egg weight, egg mass, feed consumption, feed utilization, or BW gain compared with the control diet (Table 6). Diets were formulated to be isoenergetic, with equal contents of true digestible Lys and TSAA; hence, no differences were expected.

Egg yolk color and egg composition (contents of solids, yolk, albumen, and shell) were measured as indicators of egg quality (Table 7). Of the fiber treatments, only corn DDGS affected yolk color. This observation was expected, because corn contains relatively high contents of xanthophylls, which are a primary contributor of yolk pigmentation (NRC, 1994; Leeson and Summers, 2005). As a result, the L* value of egg yolks from hens fed corn DDGS was lower during phase 1 than the yolks from control-fed hens ($P < 0.001$), indicating a darker color, and the a* values were higher during phases 1 and 3 than the yolks from control-fed hens ($P \leq 0.001$), indicating a redder color, which may be preferred by customers (Herber-McNeill and Van Elswyk, 1998). The higher a* and lower L* values of the egg yolks in this study are in agreement with those reported by Lumpkins et al. (2005) and Roberson et al. (2005) after feeding corn DDGS to laying hens. Consumption of the reduced-CP diet resulted in a greater a* value than yolks of eggs from hens fed the normal-CP diet during phases 1 and 3 ($P \leq 0.05$). The redder egg yolks from hens fed the reduced-CP diets may be explained by an increase in the consumption of corn-derived xanthophylls, because the reduced-CP diets contained a higher percentage of corn than the control diet.

There were no effects of dietary CP contents on egg composition ($P > 0.10$). However, corn DDGS resulted in an increase in the percentage of albumen compared with eggs from hens fed the control diet during phase 1 ($P < 0.05$). To further elucidate this effect of corn DDGS on egg composition, egg yolk, albumen, and shell were analyzed as grams per egg, with egg weight included as a covariate in the statistical model (data not shown). The effect of corn DDGS on albumen content persisted with a 0.5 g/egg increase in albumen weight in eggs from hens fed the corn DDGS compared with eggs from hens fed the control diet ($P < 0.05$).

Nitrogen consumption was higher for hens fed corn DDGS or WM compared with hens fed the control diet (Table 8; $P < 0.001$). The higher N consumption was expected, because amino acids in fibrous feed ingredients are typically less digestible than those in low-fiber ingredients (Kirchgessner et al., 1994; Stein et al., 2006), requiring consumption of larger amounts of total amino acids (and, therefore, N) to satisfy the requirement for digestible amino acids. The higher N consumption of the hens fed the corn DDGS or WM diet was expected to result in

Table 7. Egg quality[1]

Item	Fiber					Protein		
	Control	Corn DDGS	WM	SH	Pooled SEM	Normal	Reduced	Pooled SEM
Phase 1 yolk color[2]								
L*	75.72	74.94***	75.55	75.48	0.12	75.53	75.32	0.08
a*	5.89	6.97***	6.05	6.12	0.18	6.08^{b}	6.44^{a}	0.13
b*	47.84	47.42	47.74	47.09	0.34	47.45	47.60	0.22
Phase 2 yolk color[2]								
L*	79.65	78.40	80.07	79.98	0.87	79.09	79.46	0.61
a*	4.14	4.72	3.83	4.34	0.19	4.20	4.31	0.13
b*	50.27	50.29	50.53	50.56	0.14	50.31	50.51	0.10
Phase 3 yolk color[2]								
L*	80.67	80.11	80.69	80.69	0.18	80.56	80.52	0.13
a*	5.27	6.62***	5.25	5.26	0.25	5.16^{B}	6.03^{A}	0.18
b*	86.72	87.13	86.82	86.56	0.40	86.37^{b}	87.25^{a}	0.28
	%							
Phase 1 egg contents								
Solids[3]	20.32	20.29	19.93	20.49	0.22	20.13	20.29	0.15
Yolk	24.30	23.66	23.91	23.71	0.23	23.91	23.88	0.16
Albumen	62.43	63.32*	62.88	63.12	0.26	62.92	62.96	0.18
Shell	12.73	12.48	12.66	12.61	0.11	12.61	12.63	0.07
Phase 2 egg contents								
Solids[3]	21.91	21.60	21.59	21.64	0.12	21.71	21.66	0.09
Yolk	27.48	27.41	27.45	27.17	0.20	27.24	27.51	0.14
Albumen	59.53	59.70	59.47	60.08	0.26	59.89	59.49	0.18
Shell	12.21	12.14	12.31	12.01	0.10	12.19	12.15	0.07
Phase 3 egg contents								
Solids[3]	21.21	20.96	21.40	21.22	0.13	21.26	21.14	0.09
Yolk	28.25	27.97	28.41	28.20	0.20	28.17	28.24	0.14
Albumen	58.89	59.42	58.87	59.12	0.24	59.10	50.05	0.18
Shell	12.86	12.61	12.72	12.68	0.13	12.73	12.71	0.09

a,b Means within a row lacking a common superscript differ ($P < 0.05$), n = 64.

A,B Means within a row lacking a common superscript differ ($P \leq 0.01$), n = 64.

[1]Phase 1: 23 to 31 wk of age; phase 2: 32 to 44 wk of age; phase 3: 45 to 58 wk of age. DDGS = dried distillers grains with solubles; WM = wheat middlings; SH = soybean hulls.

[2]L* indicates dark to light, a* is a measure of green to red, and b* is a measure of blue to yellow.

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

*$P < 0.05$; ***$P \leq 0.001$; P-value from Dunnett's multiple comparison procedure comparing control to corn DDGS, WM, or SH, n = 32.

a higher N excretion than that of the control-fed hens. However, N excretion was unaffected by the corn DDGS or WM treatment ($P > 0.10$). As a result, N retention was higher for the hens fed WM ($P = 0.01$) but not corn DDGS ($P = 0.08$) compared with hens fed the control diet. Although N retention was unexpectedly negative for the control-fed hens, N retentions of the hens fed the corn DDGS, WM, or SH diets were not different from 0 ($P > 0.05$; t-test), indicating that hens fed the high-fiber diets were neither gaining nor losing body N.

Table 8. Phase 3 (45 to 58 wk of age) N balance per hen and N and DM digestibility of diets[1]

Item	Fiber					Protein		
	Control	Corn DDGS	WM	SH	Pooled SEM	Normal	Reduced	Pooled SEM
N consumption, g/d	2.33	2.64***	2.50***	2.41	0.02	2.55^{A}	2.39^{B}	0.02
N in egg, g/d	0.92	0.91	0.90	0.90	0.03	0.91	0.90	0.02
N excretion, g/d	1.61	1.68	1.49	1.54	0.07	1.66^{a}	1.49^{b}	0.05
N retention,[2] g/d	−0.18	0.03	0.10**	−0.02	0.07	−0.03	0.01	0.05
N digestibility, %	31.14	36.20	40.23*	36.16	2.73	34.75	37.11	1.93
DM digestibility, %	63.50	62.41	64.88	63.36	1.14	62.60	63.46	0.81

a,b Means within a row lacking a common superscript differ ($P < 0.05$), n = 64.

A,B Means within a row lacking a common superscript differ ($P < 0.01$), n = 64.

[1]DDGS = dried distillers grains with solubles; WM = wheat middlings; SH = soybean hulls.

[2]Nitrogen retention was calculated as N intake − N in egg − N excretion.

*$P \leq 0.05$; **$P \leq 0.01$; ***$P < 0.001$; P-value from Dunnett's multiple comparison procedure comparing control to corn DDGS, WM, or SH, n = 32.

Apparent fecal N digestibility was greater for the WM diet than the control diet (Table 8; $P = 0.05$). The higher N digestibility was not expected, because addition of high-fiber feed ingredients has been shown to lower the N digestibility (Kirchgessner et al., 1994; Jaroni et al., 1999b; Hogberg and Lindberg, 2004; Holt et al., 2006). However, the apparent fecal DM digestibility was not different for the corn DDGS, WM, or SH diets compared with the control diet ($P > 0.10$). As a result, hens fed the corn DDGS, WM, or SH diets did not excrete more manure on a DM basis compared with hens fed the control diet ($P > 0.05$). Apparent fecal N and DM digestibilities were not different for hens fed the reduced-CP diets compared with hens fed the normal-CP diets ($P > 0.10$).

There were no effects of the reduced-CP diet on egg weight, feed consumption, or BW gain during the trial (Table 6; $P > 0.10$). Contrary to expectations, however, egg production, egg mass, and feed utilization were lower from the hens consuming the reduced-CP diets compared with hens fed the normal-CP diets during phases 2 and 3 ($P < 0.05$). Because amino acid-supplemented reduced-CP diets have been fed to laying hens with no discernible effect on egg production parameters (Summers, 1993; Summers and Leeson, 1994; Keshavarz and Austic, 2004), the poorer production observed for the hens fed the reduced-CP diets in the present experiment suggests that the target amino acid values for 1 or more amino acids were set too low for the phase 2 and 3 diets. Indeed, Meluzzi et al. (2001) found that reduced-CP, amino acid-supplemented diets sustained performance for 8 wk, after which time egg production and egg mass were lower from hens fed 13.6 and 15.3% CP diets compared with hens fed 17.1% CP diets.

Nitrogen consumption was lower ($P < 0.01$) for hens fed the reduced-CP diets than that of hens fed the normal-CP diets (Table 8). This difference was expected, because the reduced-CP diets contained less N than the normal-CP diets, and hens fed the normal- or reduced-CP diets consumed similar amounts of feed ($P > 0.10$). Hens fed the reduced-CP diets had similar N content in eggs and N retention compared with that of the control-fed hens ($P > 0.10$). The decreased N consumption of the hens fed the reduced-CP diets, therefore, resulted in decreased N excretion compared with hens fed the normal-CP diets ($P < 0.05$). The lower N excretion is in agreement with results from studies in which broilers, pigs, or laying hens were fed reduced-CP diets (Kreuzer and Machmuller, 1993; Summers, 1993; Summers and Leeson, 1994; Tetens et al., 1996; Canh et al., 1997; Bregendahl et al., 2002; Shriver et al., 2003; Keshavarz and Austic, 2004). Although others have shown that lower N excretion from reduced-CP-fed animals resulted in lower NH_3 excretion (Latimier and Dourmad, 1993; Liang et al., 2005), the lower N excretion from the hens in the present study did not result in lower NH_3 emission (Roberts et al., 2007).

Results of this study showed that inclusion of 10% corn DDGS, 7% WM, or 5% SH in laying-hen diets had no adverse effects on egg production, egg quality, or N balance. Therefore, increasing the dietary fiber content may be a feasible option to mitigate NH_3 emission in a commercial egg-production operation (Roberts et al., 2007). The reduced-CP diets resulted in decreased egg production, which may be attributed to an amino acid deficiency.

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