Maximum Dietary Content of Corn Dried Distiller's Grains with Solubles in Diets for Laying Hens. Effects on Nitrogen Balance, Manure Excretion, Egg production, and Egg Quality

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Summary and Implications

An experiment was conducted with 48 laying hens to determine the effects of high dietary contents of corn dried distiller's grains with solubles (DDGS) on nitrogen and dry matter manure excretion as well as egg production and egg quality. Diets containing 0, 23, 46, and 69% corn DDGS were fed to laying hens for 8 weeks after an initial 4-week-long transition period during which the dietary contents of corn DDGS were gradually increased. Egg production, egg weight, and feed consumption were measured weekly, whereas manure excretion and egg quality was measured after feeding the treatment diets for 6 weeks. Nitrogen consumption and excretion increased with increasing dietary corn DDGS contents. Egg production decreased linearly, whereas egg weight increased linearly, resulting in no significant change in overall egg output. Feed consumption increased linearly with increasing dietary corn DDGS content, causing an increase in manure dry matter excretion. It appears from this experiment that high dietary inclusion levels of corn DDGS can be fed to laying hens without adversely affecting egg production or egg quality. However, nutrient and manure dry matter excretion will increase.

Introduction

The increased use of corn grain for ethanol production in the United States has caused a dramatic increase in corn grain prices, in turn increasing feed cost for livestock and poultry producers. There is a concern that sufficient corn may not be available for use in livestock and poultry feed or that such use will be prohibitively expensive due to competition for ethanol production. The coproduct from ethanol production, corn dried distiller's grains with solubles (DDGS), contains all the nutrients found in the corn kernel, except most of the starch, which has been fermented to ethanol and carbon dioxide. Thus, corn DDGS typically contains about 27% crude protein, 10% oil, 0.8% phosphorus, and 0.7% sulfur and is suitable as a feed ingredient for poultry and livestock. Corn DDGS is routinely fed to laying hens in commercial settings, and has been fed at up to 15 to 20% of the diet with no adverse effects on egg production.

However, the above-mentioned dietary inclusion level of corn DDGS inclusion is governed by current feed ingredient availability and price (i.e., the relative prices of corn grain, corn DDGS, and soybean meal) and do therefore not necessarily reflect inclusion levels that limit egg production or egg quality. When economic restraints are removed and only the feed ingredients' content of nutrients restrains diet formulation, as much as 70% corn DDGS can be included in a laying hen diet (depending on the desired dietary nutrient and energy contents). However, it is not known what the effects are of such high inclusion level of corn DDGS on egg production and egg quality. High dietary contents of sulfur (through high dietary inclusion levels of corn DDGS) may interfere with calcium and trace-mineral absorption and, therefore, eggshell quality. In addition, there may be some environmental ramifications of high dietary inclusion rates of corn DDGS. Typically, corn and soybean meal–based laying hens diets contain about 15 to 17% crude protein, but a balanced diet containing 50% corn DDGS will contain over 20% crude protein. Protein (or nitrogen) consumed in excess of its needs is excreted in the form of uric acid in the manure, where it is readily converted to ammonia by microbes found in the manure. Although the higher manure nitrogen may increase the manure fertilizer value, it may also negatively impact the environment through reduced air quality, ground water contamination, and eutrophication. Corn DDGS contains a relatively high amount of sulfur, which, when excreted, may lead to elevated hydrogen sulfide emissions. Both ammonia and hydrogen sulfide emissions can negatively impact egg production and worker health and is regulated by the Federal Comprehensive Environmental Response, Compensation, and Liability Act and the Federal Emergency Planning and Community Right to Know Act.

The objectives of this experiment were to investigate effects of graded dietary levels of corn DDGS on nitrogen balance and dry matter manure excretion by laying hens. In addition, egg production and egg quality were measured.

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Material and Methods

Dietary Treatments

The 4 experimental diets consisted of 4 levels of corn DDGS included in a corn and soybean meal–based diet formulated to meet or exceed the National Research Council[2] nutrient recommendations for laying hens (Table 1). The highest inclusion level of corn DDGS (i.e., 69%) was chosen in part because diets with higher corn DDGS inclusion levels could not be balanced to meet the desired nutrient contents and in part to ensure that the corn DDGS inclusion levels were equally spaced among the 4 dietary treatments. All diets contained 1.0% Celite to increase the content of acid-insoluble ash, used as an indigestible marker. The diets were formulated to be isoenergetic using nitrogen-corrected metabolizable energy values for feed ingredients published by the National Research Council,[2] except for corn DDGS for which an energy value of 2,800 kcal/kg was assigned; the non-phytate phosphorus content of the corn DDGS was estimated as 54% of total phosphorus. The diets were formulated on a true digestible amino acid basis. Prior to diet formulation, all protein-supplying feed ingredients (i.e., corn DDGS, corn, soybean meal, and meat and bone meal) were analyzed for total amino acids by ion-exchange chromatography and the contents of true digestible amino acids calculated from true digestibility coefficients listed by Ajinomoto;[3] the true lysine digestibility coefficient of the corn DDGS was estimated using the IDEA assay (Novus International, St. Louis, MO). The corn DDGS was analyzed for contents of nitrogen using the micro-Kjeldahl method on a Kjeltech 1028 distilling unit (U.S. Tecator, Inc., Herndon, PA) and the crude protein content calculated as nitrogen × 6.25 (Table 2). The corn DDGS contents of ether extract and ash were determined using a Goldfisch extraction apparatus (Laboratory Construction Company, Kansas City, MO) by ashing in a muffle furnace at 600°C for 24 hours, respectively. In addition, the contents of calcium, sodium, chloride, and sulfur were analyzed at a commercial laboratory (Eurofins, Des Moines, IA); and the corn DDGS was screened for the presence of mycotoxins at the Iowa State University Veterinary Diagnostic Laboratory (Ames, IA).

Representative samples of all diets were analyzed in duplicate for contents of nitrogen and in triplicate for contents of ether extract as previously described. In addition, the dietary contents of acid and neutral detergent fiber were analyzed using an Ankom fiber analyzer (Ankom Technology Corporation, Fairport, NY). Diet color was measured using the Hunter L,a,b color scale[4] with a Minolta color meter (Minolta Chroma Meter CR-310, Minolta Corporation, Ramsey, NJ).

Housing and Management

A total of 48 49-week-old Single-comb White Leghorn laying hens (Hy-Line W-36) was placed in metabolic cages (12 × 20 × 16 in; width × depth × height), equipped for collection of excreta, in a light-controlled, fan-ventilated room. Each cage contained 2 hens and was equipped with a steel self-feeder and a trough waterer, the latter shared between 2 adjacent cages (Figure 1). Hens were provided with 16 hours of light and 8 hours of darkness per day and the ambient temperature was maintained at 26°C throughout the study. The hens were randomly assigned to 1 of 4 experimental diets and had free access to the diets, fed in mash form, throughout the experiment. Prior to the experiment, the hens were fed a corn and soybean meal–based diet containing 10% corn DDGS for 2 weeks. Upon the start of the experiment, the hens were accustomed to the high inclusion rates of corn DDGS by gradually introducing the treatment diets over a 4-week period (Table 3). The hens were weighed at the beginning and end of the study.

Nitrogen Balance

During week 10 of the experiment (Table 3), excreta was collected twice daily for 3 days and stored at –20°C until analysis. Excreta samples were pooled within cage, freeze-dried, and allowed to equilibrate with room moisture prior to analysis. Nitrogen in the freeze-dried excreta was analyzed as described for the diets. The moisture contents of the experimental diets and freeze-dried excreta were determined in duplicate by drying at 135°C for 3 hours. The contents of acid-insoluble ash in the experimental diets and the excreta were analyzed in triplicate.

The excretion of dry-matter manure was calculated as $Manure_{Excretion} = (AIA_{Feed} \times Feed_{Consumption}) / AIA_{Manure}$, where $Manure_{Excretion}$ is the manure excreted (g), AIA_{Feed} and AIA_{Manure} are the analyzed acid-insoluble ash contents of feed and manure, respectively (%), and $Feed_{Consumption}$ is the feed consumed (g). Nitrogen excretion was calculated as $N_{Excretion} = Manure_{Excretion} \times N_{Manure}$, where $N_{Excretion}$ is the nitrogen excreted (g) and N_{Manure} is the nitrogen content of the manure (%). The amount of dietary nitrogen retained in the body and eggs was calculated as $N_{Retained} = N_{Consumption} - N_{Excretion}$, where $N_{Retained}$ is the nitrogen retained in the body and eggs (g) and $N_{Consumption}$ is the nitrogen consumed (g). Nitrogen utilization was calculated as $N_{Utitlization} = (N_{Excretion} / N_{Consumption}) \times 100$, where $N_{Utilization}$ (%) is the nitrogen utilization. The apparent fecal nitrogen digestibility was

[2]National Research Council. 1994. Nutrient requirements of poultry. 9th ed. Natl. Acad. Press, Washington, DC.

[3]True digestibility of essential amino acids for poultry (revision 7). Available at http://www.lysine.com/new/Technical%20Reports/Poultry/PoultryDigTableV7.pdf. Accessed July 26, 2006.

[4]L values indicate black (L = 0) to white (L = 100), a values indicates green (negative a values) to red (positive a values), and b indicates blue (negative b values) to yellow (positive b values).

calculated as: $N_{Digestibility} = 100 – [100 \times (N_{Excretion} / N_{Consumption})]$, where $N_{Digestibility}$ is the apparent fecal digestibility of the nitrogen contents in the diet (%). The apparent fecal dry matter digestibility was calculated as $DM_{Digestibility} = 100 – [100 \times (Manure_{Excretion} / Feed_{Consumption})]$, where $DM_{Digestibility}$ is the apparent fecal digestibility of the dry matter contents of the diet (%).

Egg Production and Egg Quality

Egg production was recorded daily, whereas feed consumption was determined twice a week throughout the experiment. Eggs collected over a 48-hour period were saved for weight determination every week and egg mass calculated as egg production × egg weight. Feed utilization was calculated as grams of egg mass produced per gram of feed consumed.

Saline solutions were prepared in a temperature-controlled room (20°C) with feed-grade sodium chloride and tap water to make densities from 1.065 to 1.096 g/cm^3 with 0.002-g/cm^3 increments between solutions. Eggs collected over a 48-hour period during week 9 of the experiment (Table 3) were sequentially placed in the saline solutions, beginning with the lowest density, until the individual eggs floated for at least 5 seconds. The density of sodium chloride in the bucket in which each egg floated was recorded as the egg's specific gravity.

The albumen height of each egg collected from a second 48-hour period during week 9 of the experiment (Table 3) were measured in a temperature-controlled room (13°C) using an electronic tripod albumen-height gauge (Technical Services and Supplies, York, UK) with the Haugh units subsequently calculated from the records of egg weight and albumen height as Haugh unit = $100 \times \text{Log}(\text{albumen height} – 1.7 \times \text{egg weight}^{0.37} + 7.57)$.

Yolk color was determined from eggs collected from a third 48-hour period during week 9 of the experiment (Table 3). Egg yolk color was measured using the Hunter L,a,b color scale as described for the treatment diets.

Egg components were determined on eggs collected over a 48-hour period during week 10 of the experiment (Table 3). Shell, yolk, and albumen were separated from each egg and weighed separately.

Manure pH

Manure was collected from all cages during week 11 of the experiment (Table 3) and kept on ice until measurement of pH. One part manure (approximately 1 g) was mixed with 10 parts double-distilled water with a vortex mixer and the pH measured using a calibrated pH meter (Accumet AR-15, Fisher Scientific, Pittsburgh, PA).

Statistical Analyses

Data were analyzed by analysis of variance (ANOVA) appropriate for completely randomized design with 4 dietary treatments and 6 replications using JMP (version 6.0.3, SAS Institute, Inc., Cary, NC). When the main effect of diet was significant, linear and quadratic orthogonal polynomial contrasts were used to evaluate treatment effects. Individual cages, each containing 2 hens, served as the experimental units. *P*-values less than or equal to 0.10 were considered significant.

Results

There we no significant differences among dietary treatments with regard to hen body weight at the beginning (1.47 ± 0.02 kg) and end (1.58 = 0.02 kg) of the experiment. The increased protein content of the corn DDGS–containing diets resulted in a significant increase in both nitrogen consumption and excretion (Table 4). The nitrogen retained in body and eggs and nitrogen utilization increased linearly with increasing dietary corn DDGS content, whereas nitrogen utilization increased quadratically. There were no significant differences in apparent fecal nitrogen digestibility, although the apparent fecal dry matter digestibility decreased linearly with increasing dietary corn DDGS content (Table 4). The manure pH decreased linearly with increasing dietary corn DDGS content (Table 4).

Egg production decreased linearly (Table 5; Figure 2), whereas the egg weight increased linearly with increasing dietary corn DDGS content (Table 5; Figure 3). As a result of the lower egg production rates and higher egg weights when corn DDGS was fed, egg mass was not affected by the dietary treatments (Table 5; Figure 4). Feed consumption rates increased linearly with increasing dietary corn DDGS content (Table 5; Figure 5), but not sufficiently to affect feed utilization (Table 5; Figure 6).

Neither the eggs' specific gravity nor their Haugh units were affected by the dietary treatments (Figures 7 and 8, respectively). The dietary treatments affected the color of the yolks significantly, with a linear decrease in lightness (L values) and a linear increase in redness (a values); Hunter b values were not affected (Figure 9). The eggshell weight was not affected by the dietary treatments, although both yolk and albumen weights increased linearly with increasing dietary corn DDGS content (Figure 10). However, when egg components were expressed as a percentage of egg weight, there were no effects of the diet (Figure 11).

Discussion

In part because of the higher feed consumption rate and in part because of the increasing crude protein content of the corn DDGS diets, nitrogen consumption was higher in hens fed the corn DDGS diets. Because the corn DDGS diets supplied more protein than that needed by the hens, nitrogen excretion also increased. Despite the increased nitrogen excretion, nitrogen retention increased, probably in part due to greater egg weights. Surprisingly, the apparent fecal nitrogen digestibility was not affected by addition of corn DDGS to the diets, although this observation agrees well

with the increased nitrogen retention. The amino acids in corn DDGS are generally considered of relatively low digestibility, and it was expected that it would be reflected in an overall reduced nitrogen digestibility of the diets. However, digestible nitrogen contributions from corn, soybean meal, and meat and bone meal may have been sufficient to counteract any negative effects on the overall diet nitrogen digestibility. Also, the drying temperature at the ethanol plant was reported to be relatively low, which would lead to improved amino acid digestibilities. The apparent fecal diet dry matter digestibility decreased linearly with increasing corn DDGS content, partially explained by an increase in the fiber contents of the diets. The lower dietary dry matter digestibility was accompanied by an increase in manure dry matter excretion. Unfortunately, the sampling and analysis procedures did not allow for measurements of the moisture contents of the manure, which is likely to be affected by the high protein and fiber contents of the diets.

Unexpectedly, the sulfur content of the corn DDGS was low (less than 0.02%), whereas corn DDGS is reported to contain between 0.3 and 1.9% sulfur due to the use of sulfuric acid to control pH in the fermentation process. However, if the dietary sulfur content increases substantially above that required by the hens, feeding high levels of corn DDGS may result in an increase in hydrogen sulfide emission from the manure. Similarly, the increased nitrogen excretion from hens fed high levels of corn DDGS may lead to an increase in ammonia emission. However, because of the low pH of the manure from corn DDGS–fed hens, ammonia emission may not increase because ammonia (NH_3) is converted to ammonium (NH_4^+) at low pH, which may reduce ammonia evaporation.[5]

The hens responded to the high-fat, high-protein corn DDGS diets by increasing egg size and decreasing rate of lay, thus maintaining egg output over time. The larger egg sizes were due to greater yolk and albumen weights both, meaning that all parts of the egg (except the eggshell) increased, also evidenced by the unchanged egg percentage composition. A high dietary sulfur content may interfere with absorption of calcium and trace minerals, in turn reducing eggshell quality, although this was not observed in the present experiment, potentially due to low dietary sulfur contents. However, with larger egg sizes, thinner eggshells that are more prone to breaking would be expected. The diets affected the yolk color, which was expected because of the high concentration of xanthophylls in corn DDGS as indicated by the darker and redder diet color values with increasing corn DDGS content.

It is not known if long-term feeding (i.e., feeding longer than the 8 to 12 weeks in the present experiment) of the treatment diets would affect egg production or metabolism of the hens. The diet with the highest content (69%) of corn DDGS was essentially devoid of starch, meaning that the hens relied solely on converting dietary amino acids to glucose through the gluconeogenesis pathway to maintain normal glucose concentrations in the blood and relying increasingly on fatty acid oxidation to supply energy. Animals fed a low-starch, high-protein, high-fat diet over a relatively long period of time may develop ketosis and fatty liver, which could influence egg production and egg quality.

Although the diets were formulated to be isocaloric, feed consumption increased with increasing dietary corn DDGS content, indicating that the metabolizable-energy value assigned to the corn DDGS (2,800 kcal/kg) may have been too high and therefore lowering the dietary energy content proportionally to the corn DDGS content. Hence, the hens may have tried to maintain energy consumption by increasing feed consumption. The corn DDGS diets contained relatively high amounts of fat, protein, and fiber, which differ widely in their energy losses as heat increment. Heat increment is not accounted for in the metabolizable energy system and it is possible that energy content and feed consumption of high-fat, high-protein, high-fiber, low-starch diets can be better predicted using the net energy system.

In conclusion, it appears that laying hen diets can be formulated with high amounts of corn DDGS without adversely affecting egg production and egg quality as long as the nutrient (and energy) contents of all feed ingredients are known and the diet is formulated on a digestible amino acid basis. A disadvantage of the high inclusion rate of corn DDGS is an increase in nutrient and dry matter manure excretion, however.

Acknowledgements

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[5]Roberts, S., H. Xin, B. Kerr, J. 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.

Table 1. Ingredient and nutrient composition of the experimental diets.

Item	Corn DDGS Treatment			
	0%	23%	46%	69%
	%			
Ingredient				
Corn DDGS	–	23.00	46.00	69.00
Corn	61.08	41.64	20.89	0.22
Soybean meal (48% CP)	19.00	15.00	12.00	9.00
Meat and bone meal (50% CP)	7.10	5.70	4.30	2.80
Vegetable oil	2.08	3.68	5.50	7.32
DL-Methionine	0.23	0.17	0.11	0.04
Calcium carbonate[1]	9.76	10.16	10.55	10.97
Sodium chloride (iodized)	0.10	–	–	–
Tracemineral premix[2]	0.30	0.30	0.30	0.30
Vitamin premix[3]	0.35	0.35	0.35	0.35
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Nitrogen-corrected metabolizable energy, kcal/kg	2850	2850	2850	2850
Crude protein[4]	17.36	18.22	20.29	21.90
Arginine (true digestible)	1.10	1.10	1.12	1.13
Histidine (true digestible)	0.39	0.41	0.45	0.48
Isoleucine (true digestible)	0.61	0.66	0.73	0.79
Lysine (true digestible)	0.88	0.85	0.85	0.84
Methionine (true digestible)	0.48	0.46	0.44	0.41
Methionine + cystine (true digestible)	0.73	0.73	0.73	0.73
Threonine (true digestible)	0.61	0.65	0.70	0.76
Tryptophan (true digestible)	0.18	0.17	0.17	0.17
Valine (true digestible)	0.72	0.78	0.86	0.93
Ether extract[4]	4.71	7.35	13.16	16.96
Linoleic acid	1.45	2.15	2.82	3.50
Neutral detergent fiber[4]	8.12	13.36	16.49	20.82
Acid detergent fiber[4]	2.85	5.33	7.70	10.02
Calcium	4.50	4.50	4.50	4.50
Phosphorus (non-phytate)	0.40	0.40	0.40	0.40
Sulfur	0.22	0.17	0.12	0.08
Potassium	0.66	0.69	0.73	0.77
Sodium	0.19	0.18	0.21	0.24
Chloride	0.28	0.24	0.26	0.27
Colorimetric values[4]				
Hunter L	66.52	58.66	51.31	43.59
Hunter a	3.06	5.72	8.20	10.03
Hunter b	21.75	25.20	25.91	23.61

[1]Supplied as a 50:50 mix of fine (0.14-mm mean diameter) and coarse (2.27-mm mean diameter) particles.

[2]Supplied per kilogram of diet: Vitamin A, 9,259 IU; vitamin D_3, 3,086 ICU; vitamin E, 15 IU; vitamin B_{12}, 12 µg; riboflavin, 6 mg; niacin, 31 mg; D-pantothenic acid, 11 mg; choline, 386 mg; vitamin K, 2 mg; folic acid, 0.5 mg; vitamin B_6, 2 mg; thiamine, 2 mg; D-biotin, 0.05 mg.

[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]Analyzed values.

Table 2. Analyzed chemical composition and mycotoxin content of the corn DDGS used in the study.

Item	Amount
	%
Crude protein	23.3
Ether extract	15.2
Calcium	0.03
Chloride	0.17
Phosphorus (total)	0.69
Sodium	0.19
Sulfur	<0.02
Ash	3.7
Lysine[1]	0.88 (82)
Methionine[1]	0.46 (90)
Threonine[1]	0.96 (82)
Tryptophan[1]	0.16 (93)
Isoleucine[1]	0.96 (87)
Aflatoxins	No detectable amount (< 10 ppb)
Vomitoxin	No detectable amount (< 1.0 ppm)
Zearalenol	No detectable amount (< 1.0 ppm)
Zearalenone	No detectable amount (< 1.0 ppm)
T-2 toxin	No detectable amount (< 1.0 ppm)

[1]Values are total amino acid contents followed by digestibility coefficients in parentheses (as determined by the IDEA assay).

Table 3. Schedule for transitioning laying hens to the experimental diets.[1]

Week of Experiment	Period	Age of hens	Corn DDGS Treatment			
			0%	23%	46%	69%
		weeks	--------- *percentage dietary corn DDGS inclusion* ----------			
–2	Pre-experiment	47	10	10	10	10
–1	Pre-experiment	48	10	10	10	10
1	Transition	49	0	23	23	23
2	Transition	50	0	23	35	35
3	Transition	51	0	23	46	46
4	Transition	52	0	23	46	58
5	Experimental	53	0	23	46	69
6	Experimental	54	0	23	46	69
7	Experimental	55	0	23	46	69
8	Experimental	56	0	23	46	69
9	Experimental	57	0	23	46	69
10	Experimental	58	0	23	46	69
11	Experimental	59	0	23	46	69
12	Experimental	60	0	23	46	69

[1]The corn DDGS inclusion rate of 35 and 58% were created by mixing equal amounts of the diets containing 23 and 46% corn DDGS and 46 and 69% corn DDGS, respectively.

Table 4. Nitrogen balance, dry matter manure excretion, apparent fecal digestibilities, and manure pH.[1]

Item	Corn DDGS Treatment				SEM[2]	P-value[3]		
	0%	23%	46%	69%		Overall	Linear	Quadratic
Nitrogen balance								
N consumption, g/day	2.84	3.20	3.69	4.21	0.09	<0.01	<0.01	0.40
N excretion, g/day	2.00	2.12	2.38	2.94	0.13	<0.01	<0.01	0.11
N retained, g/d	0.84	1.07	1.31	1.27	0.12	0.05	0.01	0.26
N utilization, %	68.8	68.3	79.5	62.8	4.0	0.05	0.72	0.06
Dry matter balance								
Dry matter consumption, g/d	95.2	97.7	101.3	105.5	2.7	0.07	0.01	0.75
Dry matter excretion, g/d	36.6	41.9	46.3	56.4	2.6	<0.01	<0.01	0.37
Apparent fecal digestibility								
Nitrogen, %	29.7	33.7	35.5	29.9	3.3	0.53	0.88	0.16
Dry matter, %	61.5	57.2	54.4	46.5	2.4	<0.01	<0.01	0.46
Manure pH	7.04	6.91	6.86	6.61	0.08	<0.01	<0.01	0.46

[1]Values are means of 6 cages, each containing 2 hens.
[2]Pooled standard error of the mean.
[3]Probability values of the main effect of diet and linear and quadratic orthogonal polynomial contrasts.

Table 5. Egg production during the 8-week-long experimental period (see also Figures 2 through 6).[1]

Item	Corn DDGS Treatment				SEM[2]	P-value[3]		
	0%	23%	46%	69%		Overall	Linear	Quadratic
Egg production, %	90.9	90.4	90.2	84.8	1.7	0.07	0.03	0.18
Egg weight, g/egg	61.8	62.4	64.5	65.2	0.8	0.03	<0.01	0.90
Egg mass, g/day	55.9	56.5	59.0	55.5	1.4	0.38	0.86	0.18
Feed consumption, g/day	106.8	108.7	108.6	116.0	2.4	0.07	0.02	0.28
Feed utilization, g/g	0.542	0.560	0.587	0.521	0.027	0.39	0.78	0.14

[1]Values are means of 6 cages, each containing 2 hens.
[2]Pooled standard error of the mean.
[3]Probability values of the main effect of diet and linear and quadratic orthogonal polynomial contrasts.

Figure 1. The 24 metabolic cages used in the experiment.

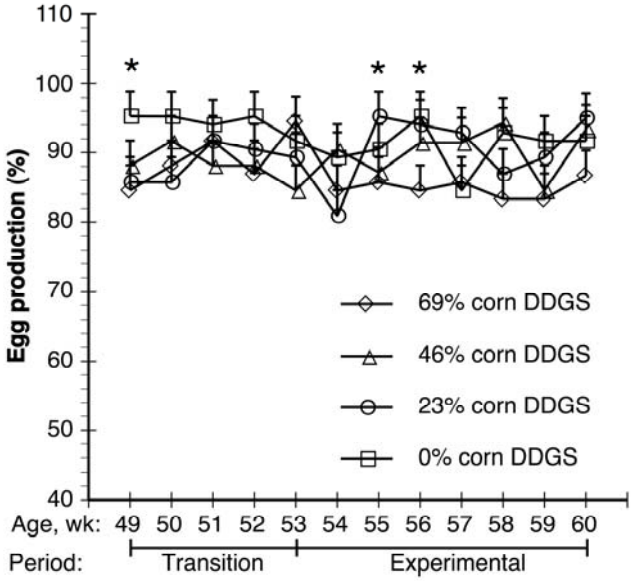

Figure 2. Weekly egg production rates during the transition and experimental periods. Values are means + pooled standard error of 6 cages, each containing 2 hens. *Two or more dietary treatments differ (P ≤ 0.10).

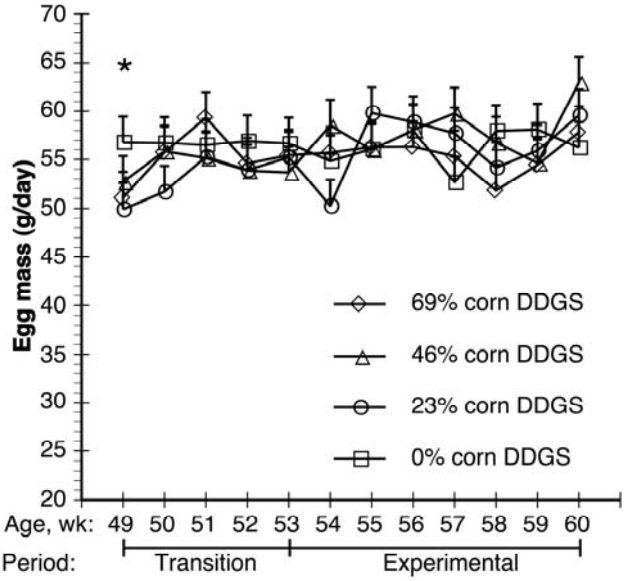

Figure 4. Weekly egg mass during the transition and experimental periods. Values are means + pooled standard error of 6 cages, each containing 2 hens. *Two or more dietary treatments differ (P ≤ 0.10).

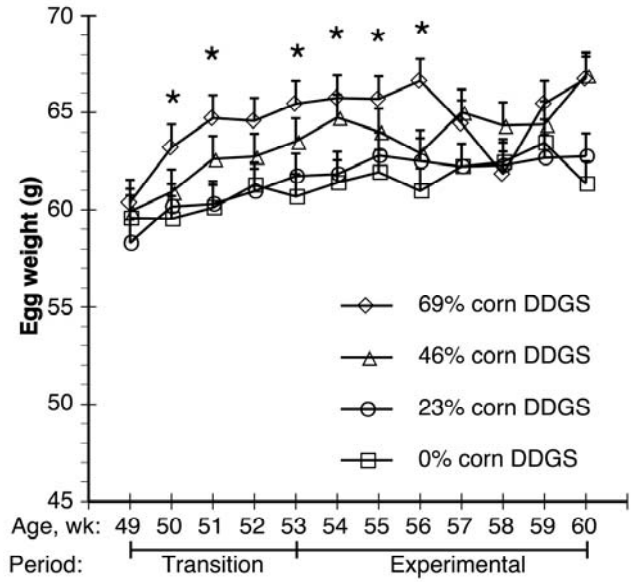

Figure 3. Weekly egg weights during the transition and experimental periods. Values are means + pooled standard error of 6 cages, each containing 2 hens. *Two or more dietary treatments differ (P ≤ 0.10).

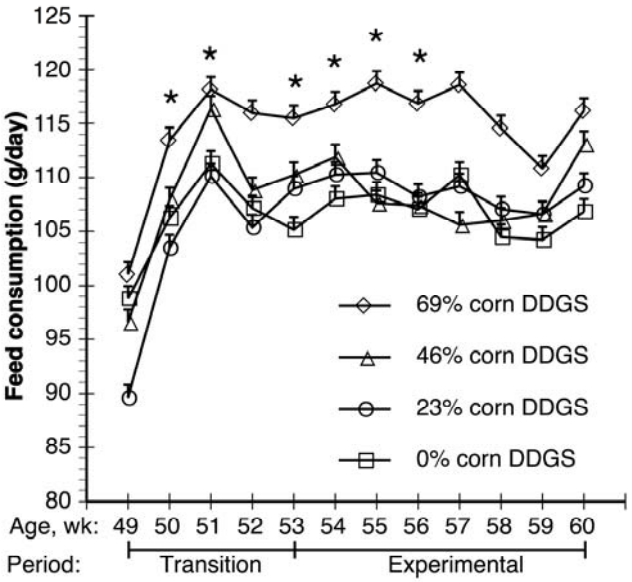

Figure 5. Weekly feed consumption rates during the transition and experimental periods. Values are means + pooled standard error of 6 cages, each containing 2 hens. *Two or more dietary treatments differ (P ≤ 0.10).

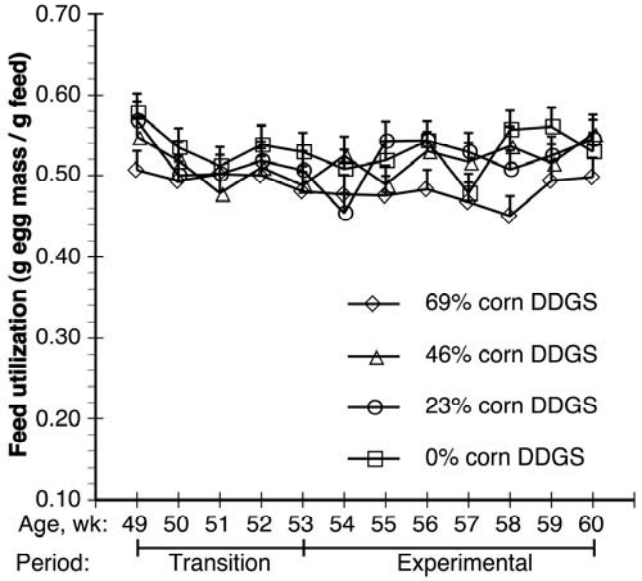

Figure 6. Weekly feed utilization during the transition and experimental periods. Values are means + pooled standard error of 6 cages, each containing 2 hens.

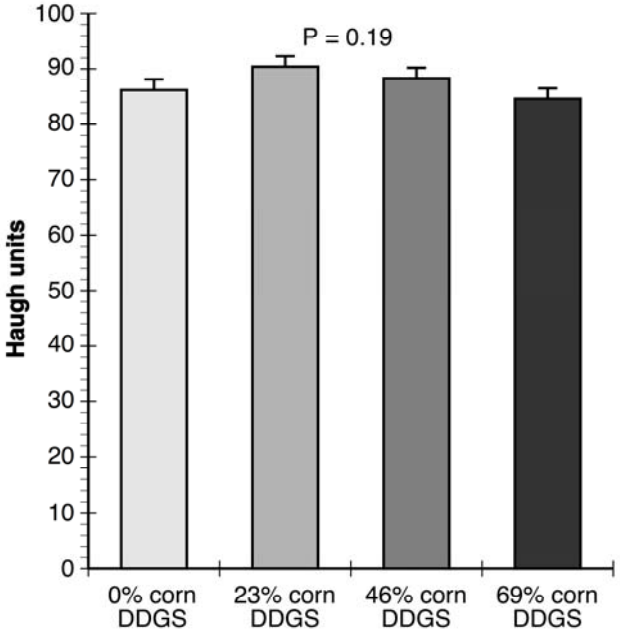

Figure 8. Haugh units of eggs collected over a 48-hour period during week 9 of the experiment (hens at 57 weeks of age). Values are means + pooled standard error of 6 cages, each containing 2 hens.

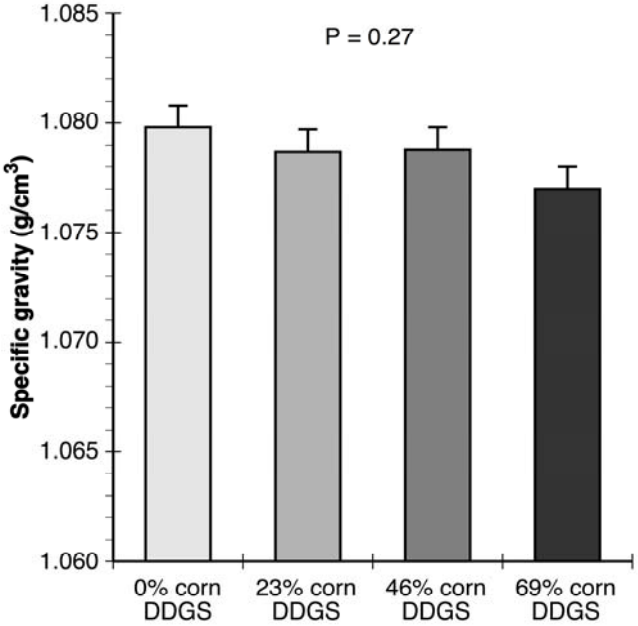

Figure 7. Specific gravity of eggs collected over a 48-hour period during week 9 of the experiment (hens at 57 weeks of age). Values are means + pooled standard error of 6 cages, each containing 2 hens.

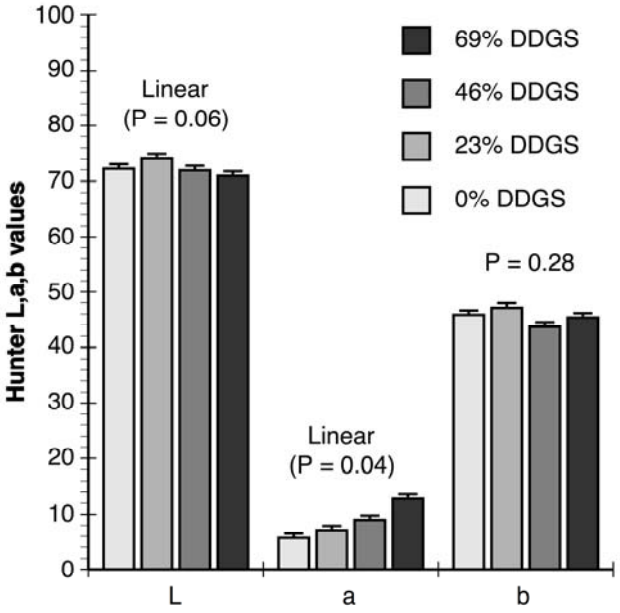

Figure 9. Hunter L,a,b color values from yolks of eggs collected over a 48-hour period during week 10 of the experiment (hens at 57 weeks of age). Values are means + pooled standard error of 6 cages, each containing 2 hens.

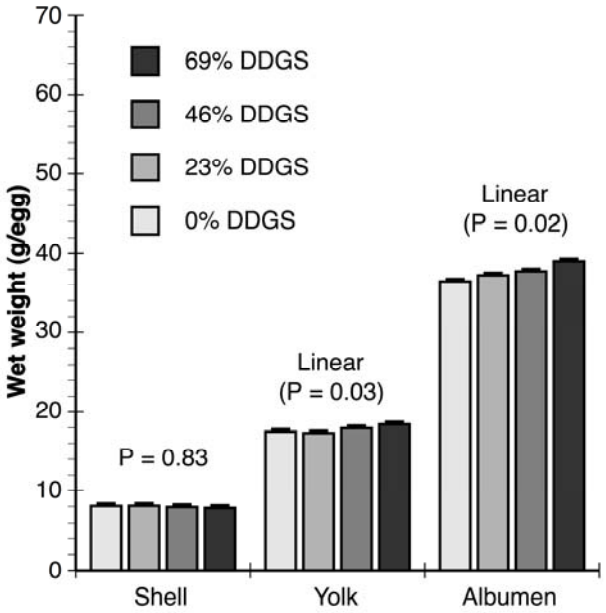

Figure 10. Composition of eggs collected over a 48-hour period during week 10 of the experiment (hens at 57 weeks of age). Values are means + pooled standard error of 6 cages, each containing 2 hens.

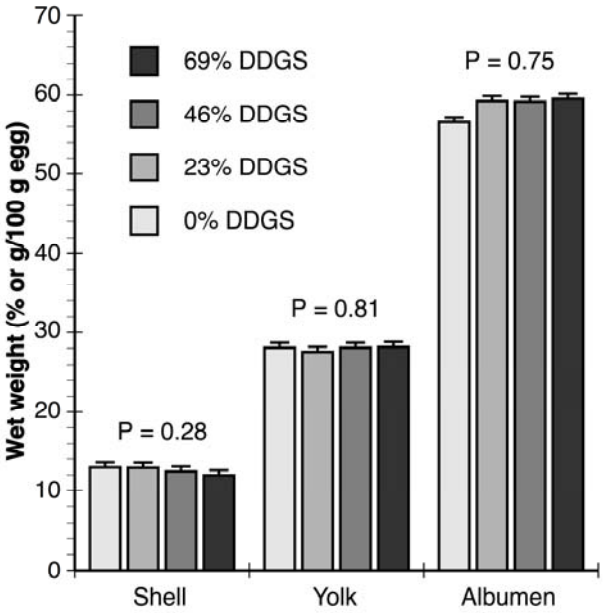

Figure 11. Composition of eggs collected over a 48-hour period during week 10 of the experiment (hens at 57 weeks of age). Values are means + pooled standard error of 6 cages, each containing 2 hens.