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Effects of Corn Distiller's Dried Grains with Solubles on Production and Egg Quality in Laying Hens

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ABSTRACT : Corn distiller's dried grains with solubles (DDGS) is a completely new feed ingredient in the Korean feed market. There is an ever increasing need for the Korean feed industry to import and make the best of it as a high protein and high energy feed ingredient. A layer feeding trial was conducted for 10 weeks to investigate the effects of addition of light-colored DDGS to layer diets on laying performance, egg qualities and yolk fatty acid composition. Also, the economics of using DDGS in the Korean situation was analyzed. Nine hundred Hy-line Brown layers, 24 weeks of age, were employed in a feeding trial consisting of four dietary treatments (0, 10, 15, and 20% DDGS), and five replicates per treatment. All experimental diets were prepared as iso-protein (17%) and iso-calorie (TMEn 2,780 kcal/kg). The use of DDGS up to 20% in layer diets did not exert any influence on feed intake, laying rate, total egg mass, mean egg weight and feed conversion ratio ($p>0.05$). The color and breaking strength of eggshell, as well as the albumin height and Haugh unit were not affected by the addition of DDGS up to 20% in the diet. The yolk color was significantly increased by DDGS supplementation ($p<0.05$). As the DDGS level increased, the oleic acid content decreased, and the linoleic acid increased ($p<0.05$) in egg yolk. The degree of saturation of yolk fatty acids was not affected by DDGS supplementation. The inclusion of light-colored DDGS up to 20% in layer diets resulted in a decrease of feed cost per kg without any undesirable effect on laying performance. In conclusion, the light-colored DDGS (L* 56.65) could be used up to 20% in layer diets without any harmful effect on laying performance, and possibly provide economic benefits to the Korean poultry industry. (**Key Words :** Corn Distiller's Dried Grains with Solubles, Layer, Egg Quality, Economics)

INTRODUCTION

Corn distiller's dried grains with solubles (DDGS) is a byproduct obtained from the milling process of corn for ethanol production. Increased emphasis on ethanol production in the United States has and will continue to increase the production of DDGS drastically (Shurson, 2003), resulting in the increased corn price in the global grain market, along with the prices of other grains with it. This will make the feed situation worse in Far Eastern countries, such as Japan, Taiwan, and South Korea, where most of the feed grains are imported. The production of DDGS, however, is expected to double in a few years, providing the opportunity to use it replacing corn and soybean meal.

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More than 8 million metric tons of DDGS will be produced in the year 2006. Some industry experts are predicting that distiller's by-product production will reach 10 to 14 million metric tons within the next few years. Most of the DDGS produced in the United States has been consumed locally as a ruminant feed, and only about 10% of DDGS produced was shipped to foreign countries (Shurson, 2003).

Recently, there have been active research works going on with DDGS to replace corn and soybean meal in swine and poultry diets. Lumpkins et al. (2004) reported that DDGS from modern ethanol plants was an acceptable feed ingredient for broiler diets and could be safely used at 6% in the starter period and 12 to 15% in grower and finisher periods. These workers also suggested a maximal inclusion level of 10 to 12% DDGS may be used in commercial layer diets (Lumpkins et al., 2005). Because of the variation in the quality of DDGS, Batal and Dale (2006) strongly suggested that confirmatory analyses should be conducted prior to using DDGS from a new supplier.

Removal of starch through ethanol fermentation raises

Table 1. Nutrient composition of corn distiller's dried grains with solubles and yellow corn

	DDGS[1]		Corn
	Analyzed	NRC (1994)	NRC (1994)
Proximate composition (%, as-fed basis)			
Moisture	12.48	7.00	11.00
Crude protein	26.53	27.40	8.50
Crude fat[2]	12.50[2]	9.00	3.80
Crude fiber	5.79	9.10	2.20
Crude ash	4.48	-	-
Calcium	0.06	0.17	0.02
Phosphorus	0.77	0.72	0.28
TMEn[3] (kcal/kg)	3,278[3]	3,097	3,470
Essential amino acids (%, as-fed basis)			
Lysine	0.76	0.75	0.26
Methionine	0.50	0.60	0.18
Threonine	1.00	0.92	0.29
Tryptophan	0.21	0.19	0.06
Fatty acid composition (%)			
Palmitic acid	1.71	1.80	0.62
Stearic acid	0.28	0.09	0.10
Oleic acid	3.26	2.25	1.17
Linoleic acid	6.88	4.77	1.82
Density (g/L)	490		
Hunter's color values			
L*	56.65		
a*	12.90		
b*	42.67		

[1] A private logistics company collected 5 metric tons of light color DDGS from several ethanol plants in the mid-western area of the U.S. and shipped in a container box to Korea.
[2] Extracted 3 h with petroleum ether (AOAC, 1995).
[3] Calculated value from chemical composition of DDGS.
TMEn (kcal/kg) = 3.53×crude protein (g)+9.00×crude fat (g) +2.65×non-starch polysaccharide (g).

the various nutrient contents including xanthophyll. Roberson et al. (2005) reported that dietary DDGS could make the yolk color denser. Due to the uncertainty of DDGS quality, together with the high cost of transportation and handling, only minimal amounts of DDGS was imported and used in poultry feeds in South Korea for a test case. Thus, our primary purpose was to evaluate the effects of feeding an elevated quantity of light-colored (high quality) DDGS in commercial laying hen rations, and on the economics in Korean situation.

MATERIALS AND METHODS

Diets and treatments

Due to the unavailability of DDGS in Korean feed market, a Korean feed company imported 5 metric tons of DDGS from the U.S. for a test case. A private logistics company collected light-colored DDGS from several ethanol plants in the mid-western area of the U.S., and shipped to Korea in a container box. Proximate composition of the DDGS was analyzed by the method of AOAC (1995). Amino acid composition of the DDGS and experimental diets were determined according to standard program (AOAC, 1984). The samples were hydrolyzed with 6 M HCl in a vacuum sealed tube at 110°C under nitrogen atmosphere for 24 h. The composition was measured by using Eppendorph LC 3000 Amino Acid Analyzer (Eppendorf-Biotronic, Hamburg, Germany). The physico-chemical properties of DDGS used in this trial are shown in Table 1. The DDGS used in this feeding trial had Hunter's color values of L* = 56.65, a* = 12.90, and b* = 42.67. There were four diet treatments (0, 10, 15, and 20% DDGS), and five replicates per treatment. All experimental diets were prepared to contain iso-protein (17%) and iso-calorie (TMEn 2,780 kcal/kg) as shown in Table 2. A commercial feed program (Bestmix 5.04, Adifo b.v., Maldegem, Belgium) was used to formulate the least-cost experimental diets for economic analysis.

Housing and managements of birds

Part of a commercial winch-type open-sided layer barn with cross-ventilation system, which had been holding about four thousand 24-wk-old beak-trimmed Hy-line Brown layers in 3-tier laying cages, was rented for this trial. Nine hundred layers housed in cages facing the same side of a corridor were allotted to 20 replicates, 45 birds per replicate, according to completely randomized design. A replicate consisted of 9 cages (52 cm W×52 cm D×45 cm H), accommodating 5 birds per cage. The layer feeding trial was conducted for 10 weeks during the hot summer season (from July to September, 2006). Feed troughs were partitioned by allocating an empty cage between all replicates. Experimental diets were offered manually and the hens were allowed to feed and nipple waterer *ad libitum*. Feed intake was measured weekly. Daily egg collection from each replicate was done manually at 15:00, the number was counted, and weighed in bulk. The daily lighting schedule was 17 L:7 D throughout the trial. When mortality occurred, which reached 2.2% (20 birds) at the end of the trial, hen-day egg production and feed intake were adjusted accordingly.

Measurements and analyses

At the 7th week of the trial, when the layers were 30 wk of age, 25 eggs were chosen randomly from daily collection of each treatment, 5 eggs per replicate. Various physical characteristics of eggs, such as weight, egg shell color, albumen height, yolk color, and Haugh unit score were measured electronically by an automatic egg quality measurement system (QCM+ System, Technical Services and Supplies, York, England). For yolk color, egg yolks were separated from the albumen and placed on small white bowl underneath of QCC yolk colorimeter (Technical

Table 2. Formula of experimental diets of layers

	DDGS				Ingredient
	0%	10%	15%	20%	price[1]
Ingredients	%				won/kg
Yellow corn	58.88	55.27	52.82	48.79	151.8
Wheat middling	-	-	-	1.95	131.9
Soybean meal	26.08	20.65	18.05	15.07	241.6
Rapeseed meal	2.00	2.00	2.00	2.00	156.4
Animal fat	2.10	1.08	0.80	0.80	520.0
Lysine-HCl	-	0.29	0.46	0.64	425.0
DL-methionine	0.17	0.15	0.14	0.14	2,250.0
Salt	0.28	0.25	0.25	0.25	104.0
Limestone	8.50	8.75	9.12	9.25	30.0
Dicalcium phosphate	1.68	1.25	1.05	0.80	328.0
Mineral premix[2]	0.20	0.20	0.20	0.20	600.0
Vitamin premix[3]	0.06	0.06	0.06	0.06	3,060.0
Choline Cl (50%)	0.05	0.05	0.05	0.05	970.0
DDGS[4]	0	10.00	15.00	20.00	219.4
	100.0	100.0	100.0	100.0	
Calculated composition (%, as-fed basis)					
Moisture	10.83	11.27	11.28	11.39	
Crude protein	17.00	17.00	17.00	17.00	
Crude fat	4.78	5.15	5.57	6.26	
Crude fiber	2.72	2.92	3.02	3.24	
Crude ash	12.91	12.83	13.12	13.09	
Calcium	3.70	3.70	3.82	3.80	
Phosphorus	0.62	0.58	0.55	0.54	
TMEn (kcal/kg)	2,780.00	2,780.00	2,780.00	2,780.00	
Essential amino acids (%, as-fed basis)					
Lysine	0.88	0.87	0.87	0.87	
Methionine	0.44	0.43	0.43	0.42	
Threonine	0.64	0.63	0.63	0.63	
Tryptophan	0.21	0.19	0.19	0.18	
Feed cost (won/kg)	182.23	179.61	179.04	179.12	
Density[5] (g/L)	711	700	675	657	

[1] Prices of ingredients in June 2006 (won/kg).
[2] Provided followings per kg of diet: Cu, 10 mg; Fe, 80 mg; Mn, 80 mg; Zn, 80 mg; I, 0.9 mg; Se, 0.2 mg; Co, 0.5 mg.
[3] Provided followings per kg of diet: vit. A, 12,000 IU; vit. D_3, 3,000 IU; tocopherol 15 mg; vit. K_3, 2 mg; thiamin, 2.0 mg; riboflavin, 6.0 mg; pyridoxine, 2 mg; vit. B_{12}, 0.03 mg; folic acid, 1.0 mg; biotin, 0.15 mg; niacin, 45 mg; D-Ca pantothenate, 15 mg; antioxidant, 0.5 mg.
[4] See Table 1. [5] Density of experimental diets.

Services and Supplies, York, England). The instrument measures the ratio of red, green and blue light reflected from the yolk when illuminated by a flashed white light and automatically compares these values with known percentages of the 1 to 15 colors of the Roche color fan score which are pre-programmed into the colorimeter. The yolk reflective color was expressed in level of 1 to 15. Eggshell breaking strength of each egg was determined by Egg Shell Force Gauge (model-II, Robotmation Co., LTD, Japan). The eggs were placed horizontally in a cradle under a sensor load and the load applied pressure to the eggs until the shell fractured. The force needed to fracture the eggs was automatically recorded in kg. Data from a replicate were averaged to give one value per replicate.

In order to determine fatty acid composition of yolk, another 25 eggs were chosen randomly from daily collection of each treatment, 5 eggs per replicate. The selected yolks of 5 eggs per replicate were pooled and homogenized to give one yolk sample per replicate. Total lipids were extracted using the procedure of Folch et al. (1957) and methylated by 14% methanolic boron trifluoride (Morrison and Smith, 1967). The fatty acid composition was measured by gas chromatography (Agillent 6890, Agillent Technologies, Inc., CA, USA) equipped with HP-INNOWAX column (30 m×0.25 mm×0.25 μm). Initial temperature of oven was 100°C for 2 min, allowing increase 4°C/min until a final temperature of 245°C was reached and kept for 20 min. Temperature of the injector and detector was 260 and 300°C, respectively. Nitrogen gas was used as carrier gas and split ratio was 15:1.

The Hunter's color L* (lightness), a* (redness), and b* (yellowness) values of the DDGS used in this experiment were measured by Color Difference Meter (spectrophotometer CM-3500d, Minolta Co., Ltd. Osaka

Table 3. Effects of corn distiller's dried grains with solubles in layer diets on the performance of layers during 24 to 33 wk of age

Items	DDGS[1]			
	0%	10%	15%	20%
Feed intake (g/bird/day)	113.8±1.60[4]	113.6±2.04	113.2±1.68	114.7±1.52
Laying rate[2] (%)	91.07±7.01	86.92±9.86	88.37±8.27	87.68±8.11
Egg weight (g/egg)	59.48±3.45	59.48±3.52	59.44±3.29	59.53±3.41
Total egg weight (kg)	170.0±4.26	164.2±4.59	165.8±4.08	164.7±8.75
Total feed intake/total egg weight	2.11±0.03	2.18±0.09	2.15±0.03	2.20±0.09
Mortality[3]	6	5	4	5

[1] See Table 1. [2] Hen-day egg production rate.
[3] No. of dead birds during 10-wk feeding trial. Initially, 225 birds were allotted to each treatment. [4] Mean±SD.

Japan) through computerized Spectra Magic software system (Version 2.11., Minolta Cyberchrom Inc., Osaka, Japan). Calibration was done before measurement with black and white tiles. Approximately 5 g of DDGS was packed in quartz petri dish (CM-A129, Minolta Co., Ltd. Osaka, Japan) and mean value was reported after 5 measurements.

Statistical analyses

All data were subjected to one-way ANOVA procedures for completely randomized design, using the GLM procedure (SAS, 2000) at the pre-set level of 5%, and polynomial contrast (lineal, quadratic, and cubic) when significant.

RESULTS AND DISCUSSION

Nutrient composition of diets

Nutrient composition of DDGS was shown in Table 1. Contents of crude protein and crude fat, and fiber were 26.53, 12.50, and 5.79%, respectively. Generally, protein in DDGS can vary from 24-29% (Dale and Batal, 2005). Lysine, one of the essential amino acids, was contained 2.9 times higher than that of corn.

Cromwell et al. (1993) assessed the degree of variability in the physical properties and chemical composition of various sources of DDGS, and related them to the nutritional values of chicks and pigs. They suggested that color may be an indicator of DDGS quality or amino acid availability or both. Roberson et al. (2005) suggested that digestibility of lysine is a variable that needs to be monitored in DDGS as it can be quite variable especially when color is different. A significant amount of lysine had been destroyed during processing and made the DDGS darker (Dale and Batal, 2005). However, Roberson et al. (2005) also insisted that if a light ("golden") color is maintained, the digestibility of lysine would not be a serious issue for the inclusion of DDGS at 15% or below. The DDGS used in this experiment were light-colored (golden), high quality ones with a color value of L* = 56.65, a* = 12.90, and b* = 42.67 (Table 1). In fatty acid composition, unsaturated fatty acids were dominant and the ratio of saturated fatty acid and unsaturated fatty acid was 1:4.3.

Composition of experimental diets and its price were shown in Table 2. The diets contained 17.0% crude protein and showed 2,780 kcal/kg of TMEn. Feed cost and density of the diets were reduced dose dependently.

Laying performance

No differences in feed intake, average egg weight, total egg weight, and feed conversion ratio (feed intake/total egg weight) were found among dietary treatments as shown in Table 3 ($p>0.05$). Bregendahl and Roberts (2006) reported that 23-week-old Hy-line layers fed 10% DDGS diet showed similar laying rate to that of the control (0% DDGS diet), supporting the result of this experiment. Roberson et al. (2005) observed that layers fed diets containing 0, 5, 10, and 15% DDGS maintained their laying rate most of the time, but decreased the egg production as the level of DDGS increased at 52 to 53 weeks of age. More research works are necessary on the age effects with different dietary levels of DDGS.

The density of the diets decreased as the level of DDGS increased (Table 2), probably decreasing the laying rate numerically but non-significantly (Table 3). Lumpkins et al. (2005) reported that hens fed a commercial diet (crude protein 18.5%, ME 2,871 kcal/kg) or low-density diet formulated to contain 15% DDGS (crude protein 17.0%, ME 2,805 kcal/kg) for 25 to 43 weeks of age showed similar laying performance between them. However, significantly low hen-day egg production was found through 35 week of age when hens were fed low-density diet with 15% DDGS. The color values of their DDGS sample were L* = 58.52, a* = 6.38, and b* = 20.48.

Physical characteristics of eggs

In Table 4 are shown the various physical characteristics of eggs from hens fed graded levels of DDGS. No differences in weight, strength, and color of eggshell were detected. In addition, DDGS did not affect both the albumin height and Haugh unit.

The yolk color was increased as the levels of DDGS increased up to 20% (linear, $p<0.05$). Roberson et al. (2005)

Table 4. Effects of corn distiller's dried grains with solubles in layer diets on the physical qualities of eggs

Items	DDGS[1]			
	0%	10%	15%	20%
Eggshell weight (g/egg)	7.30±0.62[4]	7.25±0.68	7.60±0.66	7.16±0.69
Eggshell strength (kg/cm^2)	3.70±0.78	3.65±0.54	3.91±0.43	3.62±0.79
Eggshell color[2] (%)	34.2±3.66	32.5±2.89	32.7±3.21	32.9±2.04
Albumen height (mm)	6.27±1.32	6.17±1.41	5.62±1.25	5.69±1.25
Haugh units	76.9±9.18	76.4±9.38	71.8±11.21	73.2±10.25
Yolk color (Roche)[3]	7.48±0.51^c	7.96±0.61^b	8.60±0.58^a	8.84±0.75^a

[1] See Table 1. [2] A percentage reading between black (0%) and white (100%).
[3] Yolk color was linearly increased as DDGS level increased ($p<0.05$). [4] Mean±SD.

Table 5. Effects of corn distiller's dried grains with solubles in layer diets on the chemical composition of yolk lipid

Items	DDGS[1]			
	0%	10%	15%	20%
Total fat (%)	28.89±0.57[6]	29.42±0.77	29.52±0.65	29.13±0.41
Fatty acid composition (% of total fat)				
Palmitic acid	25.71±0.54	25.78±0.44	25.50±1.24	25.56±0.71
Stearic acid	8.68±0.74	8.50±0.25	8.03±0.52	8.65±0.77
Oleic acid[2]	45.17±1.21^a	42.32±1.35^b	39.98±2.11^c	38.88±0.79^c
Linoleic acid[3]	11.66±0.40^c	15.54±1.06^b	18.26±0.83^a	18.60±1.06^a
SFA[4]	36.93±0.75	36.46±2.03	37.31±1.33	37.37±1.29
UFA[5]	62.63±1.29	63.07±0.75	63.54±2.03	62.69±1.33

[1] See Table 1. [2] Oleic acid was linearly increased as DDGS level increased ($p<0.05$).
[3] Linoleic acid was linearly increased as DDGS level increased ($p<0.05$). [4] Total saturated fatty acid.
[5] Total unsaturated fatty acid. [6] Mean±SD.

Table 6. Economic analysis for egg production in hens fed diets supplemented with DDGS[1]

Items	DDGS[1]			
	0%	10%	15%	20%
Feed cost[2] (won/kg)	182.23	179.61	179.04	179.12
Total feed intake/total egg weight[3]	2.11	2.18	2.15	2.20
Feed cost[4] (won/kg egg)	384.51	391.55	384.94	397.65
	(100.00)	(101.83)	(100.11)	(103.42)

[1] See Table 1. [2] See Table 2
[3] See Table 3. [4] Feed cost (won/kg egg) = feed cost (won/kg)×(total feed intake/total egg weight).

also reported very similar results, indicating that dietary DDGS can make the yolk color denser. Removal of starch through ethanol fermentation raises the various nutrient contents including xanthophyll. The xanthophyll contents of corn and DDGS are 17 mg/kg (NRC, 1994) and 30 mg/kg (Roberson et al., 2005), respectively, alleviating the need to use extra pigments in layer diets.

Fatty acid composition of egg yolk

As shown in Table 5, DDGS did not exert any influence on the crude fat content of egg yolk. No significant difference was found in palmitic and stearic acid contents in egg yolk among the four treatments. However, oleic acid decreased and linoleic acid increased (linear, $p<0.05$) in egg yolk as the DDGS levels increased up to 20% level, reflecting the high level of linoleic acid in DDGS (Table 1). Both saturated and unsaturated fatty acids contents of yolk were not affected by DDGS supplementation.

Economics of DDGS

As shown in Table 1, the energy value of TMEn 3,278 kcal/kg was used for DDGS in this experiment, which was much higher than those vlaues reported by Roberson et al. (2005, 2,894 kcal/kg) and Batal and Dale (2006, 2,820 kcla/kg). All experimental diets were formulated to be iso-calorie and iso-protein by using a commercial feed mix program as shown in Table 2. The costs of feed (won/kg) decreased by the inclusion of DDGS (Table 2). The results of feeding trial showed no difference in laying performance (Table 3) among dietary treatments containing graded levels of DDGS up to 20%. Rather the pigmentation and linoleic acid content of yolk increased gradually by the increased levels of DDGS supplementation (Tables 4 and 5). This indicates that high quality DDGS could effectively be used up to 20%, replacing corn and soybean meal in layer diets.

Another approach is to compare the feed cost needed to produce unit weight of egg as shown in Table 6. The feed cost per kg egg increased somewhat by the use of DDGS, especially at the 20% level of DDGS. However, the feed cost per kg egg of 15% DDGS supplementation group was very much comparable to that of no DDGS supplementation group.

In conclusion, poultry industry could expand the use of DDGS up to 20% without any harmful effect on the laying performances, however for economic reason as indicated, 15% DDGS inclusion would be desirable for the rations.

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REFERENCES

Association of Official Analytical Chemists. 1995. Official Method of Analysis. 16th ed. Association of Official Analytical Chemists. Washington, DC.

Association of Official Analytical Chemists. 1984. Official Methods for Analysis. 14th ed. Association of Official Analytical Chemists. Arlington, USA.

Batal, A. B. and N. M. Dale. 2006. True metabolizable energy and amino acid digestibility of distillers dried grains with solubles. J. Appl. Poult. Res. 15:89-93.

Bregendahl, K. and S. Roberts. 2006. Nutritional strategies to reduce ammonia emissions from laying hens. Proc. Midwest Poultry Federation Convention, St. Paul, MN. March 21-23,

Cromwell, G. L., K. L. Herkelman and T. S. Stahly. 1993. Physical, chemical, and nutritional characteristics of distillers dried grains with solubles for chicks and pigs. J. Anim. Sci. 71:679-686.

Dale, N. M. and A. B. Batal. 2005. Distiller's grains: focusing on quality control. Egg Industry, April, 12-13.

Folch, J., M. Lees and G. N. Slaon-Stanley. 1957. A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. 226:497-509.

Lumpkins, B. S., A. B. Batal and N. M. Dale. 2004. Evaluation of distillers dried grains with solubles as a feed ingredient for broilers. Poult. Sci. 83:1891-1896.

Lumpkins, B. S., 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.

Morrison, W. R. and L. M. Smith. 1967. Preparation of fatty acid methylesters and dimethylacetals from lipid with boron fluoride methanol. J. Lipid Res. 5:600-608.

National Research Council. 1994. Nutrient Requirements of Poultry (9th Ed.). National Academy Press, Washington, DC.

Roberson, K. D., J. L. Kalbfleisch, W. Pan and R. A. Charbeneau. 2005. Effect of corn distillers dried grains with solubles at `various levels on performance of laying hens and egg yolk color. Poult. Sci. 84:44-51.

SAS. 2000. SAS/STAT User's Guide: Version 6. SAS Institute Inc., Cary, North Carolina.

Shurson, J. 2003. The value and use of distillers dried grains with solubles (DDGS) in livestock and poultry ration. http://www.ddgs.umn.edu/ Accessed Jan. 2005.