Dietary inclusion level effects of distillers dried grains with solubles on broiler meat quality

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ABSTRACT A completely randomized design with 7 replications (n = 7, treatments = 5 with 8 subsamples per treatment) was used to evaluate the effects of feeding various levels of distillers dried grains with solubles (DDGS; 0, 6, 12, 18, and 24%) on broiler breast and thigh meat quality. Broilers were harvested in a pilot scale processing plant with commercial prototype equipment at 42 d of age. The right half of each breast was evaluated for pH, instrumental color, cooking loss, proximate analysis, and tenderness. The left half of each breast was used for consumer acceptability testing. Thigh meat was evaluated for proximate composition, fatty acid composition, and TBA reactive substances. Breast meat from broilers that were fed DDGS had a higher ($P < 0.05$) pH than those from the control diet. In addition, the 18 and 24% DDGS treatments yielded breast meat with higher ($P < 0.05$) pH values than the 6% DDGS treatment. No differences existed ($P > 0.05$) among breast meat from the different treatments with respect to cooking loss, instrumental color, and consumer acceptability, but breast meat from the control (0% DDGS) treatment had slightly lower ($P < 0.05$) shear force than breast meat from the 18 and 24% DDGS treatments. In addition, no differences ($P > 0.05$) existed among proximate composition of breast and thigh meat from the control and DDGS treatments. As DDGS concentration increased, there was a linear increase ($P < 0.05$) in linoleic and polyunsaturated fatty acids, which indicates a greater potential for lipid oxidation. The TBA reactive substances values were greater ($P < 0.05$) for the 18 and 24% DDGS treatments at d 5 when compared with the control and 6% DDGS treatments, which indicates increased oxidation. Overall, data suggest that all treatments yielded high-quality breast meat and that thigh meat quality was similar among treatments containing 0 to 12% DDGS, but higher inclusion levels led to thigh meat that was more susceptible to oxidation.

Key words: distillers dried grains with solubles, meat quality, proximate composition, fatty acid composition, thiobarbituric acid reactive substance

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INTRODUCTION

An increase in ethanol production over the last 5 to 10 yr has led to an increased supply of distillers dried grains with solubles (**DDGS**) that is available for livestock feed (AMS, 2007; Noll et al., 2007). Researchers have previously reported that broilers can be fed 6% DDGS during the starter period (Lumpkins et al., 2004) and 12 to 15% DDGS during the finishing stage without affecting carcass composition or growth (Lumpkins et al., 2004; Wang et al., 2007a,b). Corzo et al. (2009) recently reported that 8% inclusion of DDGS in diets fed until 42 d of age caused no differences in breast meat quality as determined by pH at 15 min and 24 h postmortem, instrumental color (L*), cooking loss, and shear force. In addition, a slight preference in consumer acceptability occurred for the treatment that was not fed DDGS over the 8% DDGS treatment, but on average, breast meat from both the DDGS- and non-DDGS-fed broilers were moderately acceptable to consumers. However, there were no differences in acceptability of breast meat from broilers that were fed DDGS and the control treatment among consumers that had a high degree of liking for chicken breast (>80% of consumers; Corzo et al., 2009).

Even though minimal published research could be located on the effects of feeding DDGS on broiler meat quality, Whitney et al. (2006) and Widmer et al. (2008) reported that the inclusion of 10% DDGS could be used in swine grower-finisher diets without affecting growth performance, carcass characteristics, or meat quality. Whitney et al. (2006) also stated that 20 to 30% DDGS inclusion in the diet resulted in decreased growth per-

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formance but had minimal effects on meat quality. In contrast, Widmer et al. (2008) reported that feeding 20% DDGS had minimal affects on meat quality with the exception of decreased belly firmness, an indicator of decreased bacon quality and increased percentage of polyunsaturated fatty acids in the meat. Feeding broilers 20 to 30% DDGS may not affect breast meat quality similarly to pork meat due to the low percentage of fat that is in the breast but may potentially lead to quality problems in thigh meat because the fat content is higher than that of breast meat.

Water-holding capacity, color, pH, tenderness, and sensory acceptability are commonly used to evaluate broiler breast meat quality because consumers prefer meat that is juicy, tender, and not pale (McKee and Sams, 1997; Van Laack et al., 2000; Schilling et al., 2003; Fletcher and Smith, 2006). Because some fatty acids from feed are deposited directly in the muscle and other body tissues, diet directly affects the composition of broiler meat, especially thigh meat due to higher fat percentages when compared with breast meat (Wood and Enser, 1997). Therefore, increased concentration of polyunsaturated fatty acids in the feed, in free form or in triglycerides, can lead to higher concentrations of polyunsaturated fatty acids in the muscle tissue and thus increases the oxidation potential and potentially decreases the shelf-life of the resulting meat (Adams et al., 1994; Cortinas et al., 2004; Suksombat et al., 2007). Corzo et al. (2009) previously reported that inclusion of 8% DDGS in the diet caused thigh meat to have higher concentrations of linoleic and polyunsaturated fatty acids, which contributed to very slight increases in oxidation over refrigerated storage time. Because 8% DDGS inclusion only caused slight differences in meat quality, it is important to perform research to determine if greater amounts of DDGS can be fed to broilers without negatively affecting meat quality. This is of vital importance because feeding higher levels of DDGS could decrease feed costs for poultry producers due to the current availability of DDGS for use as a component of poultry feed and also because of current price fluctuations of feed ingredients. Therefore, research was performed to evaluate the following objectives: 1) the effects of feeding various and higher levels of DDGS (0, 6, 12, 18, or 24%) on the color, pH, water-holding capacity, tenderness, proximate composition, and sensory acceptability of broiler breast meat and 2) the effects of feeding different levels of DDGS (0, 6, 12, 18, or 24%) on the proximate composition, fatty acid composition, and oxidative stability of thigh meat.

MATERIALS AND METHODS

Treatments

Five treatments that differed in the percentage of DDGS that was included in the diet were used in this experiment. The broilers were fed diets formulated to resemble industry ingredient and nutrient specifications. Diets were based primarily on corn, soybean meal, and meat and bone meal and contained 0, 6, 12, 18, or 24% DDGS. Diets were formulated to be isocaloric and similar in all limiting amino acids and other nutrients (Table 1) and were formulated to meet or exceed NRC (1994) nutrient recommendations. Diets were offered in 2 feeding phases, starter and grower, in crumbles from 0 to 21 d and pellets from 21 to 42 d of age. Table 1 displays only the ingredient and nutrient composition of the lowest- (0%) and highest-containing DDGS (24%) experimental diets because they were blended at various proportions to generate the 6, 12, and 18% DDGS diets.

Bird Husbandry

A total of 420 Ross × Ross 708 male broiler chicks were obtained from a commercial hatchery and distributed equally across 40 floor pens so that each treatment was replicated 7 times with 12 broilers each (0.09 m^2/bird). Chicks were vaccinated at the hatchery for Marek's disease, Newcastle disease, and infectious bronchitis. Each pen was equipped with a hanging feeder, a nipple drinker line, and built-up litter (previously used soft wood shavings). Birds consumed feed and water on an ad libitum basis, and experimental diets were provided in pellet form. Ambient temperature program was maintained at 33°C at placement until 4 d of age, 32°C from 5 to 9 d of age, 29°C from 10 to 14 d of age, 27°C from 15 to 23 d of age, 25°C from 24 to 28 d of age, 23°C from 28 to 35 d of age, and 20°C from 35 to 42 d of age. Photoperiod followed a continuous schedule with lighting intensities of 30 lx from 0 to 7 d of age, 10 lx from 7 to 22 d of age, and 3 lx from 22 to 42 d of age, and light intensity was verified at bird level (30 cm) using a photometric sensor with NIST-traceable calibration (Extech Instruments, Waltham, MA). All animal procedures were approved by the University's Institutional Animal Care and Use Committee.

Sample Preparation

At 42 d of age, 8 broilers from each of 5 treatments within 7 replications (total of 56 Ross × Ross 708 birds per treatment) were randomly selected for harvesting and whole breast and thigh removal at 4 h postmortem. Broilers were hung by their feet in steel shackles and were electrically stunned by manually placing their heads in a saturated saline bath (11.5 V, <0.5 mA alternating to direct current for 3 s). The shackle line speed was constant and set so that approximately 22 broilers were stunned per minute. Unilateral neck cutting was manually performed immediately after stunning, and bleeding lasted for 140 s. Upon completion of exsanguination, the broilers were scalded at 53.3°C for 191 s, picked for 35 s using a rotary drum picker (Baader-Johnson, Kansas City, KS), and then mechanically eviscerated. After harvest, all broiler carcasses were stored in ice water in metal containers (173 cm in

Table 1. Composition of experimental diets (% as is)[1]

	Starter phase (0 to 21 d)		Grower phase (21 to 42 d)	
Item	0% DDGS	24% DDGS	0% DDGS	24% DDGS
Ingredient				
Corn	59.191	47.657	62.586	49.613
Soybean meal (48%)	33.378	20.285	29.678	18.243
DDGS	—	24.0	—	24.0
Poultry oil	2.519	2.901	3.008	3.456
Meat and bone meal (50%)	2.0	2.0	2.0	2.0
Dicalcium phosphate	1.258	0.945	1.016	0.489
Calcium carbonate	0.455	0.827	0.702	0.983
Sodium chloride	0.455	0.352	0.457	0.354
DL-Methionine	0.29	0.289	0.175	0.164
Vitamin-mineral premix[2]	0.25	0.25	0.25	0.25
L-Lysine HCl	0.116	0.373	0.076	0.332
Coccidiostat[3]	0.05	0.05	0.05	0.05
L-Threonine	0.037	0.071	—	0.067
Calculated composition				
CP (%)	23.9	23.3	21.0	20.6
AME (kcal/kg)	3,100	3,100	3,150	3,150
Ca (%)	0.90	0.90	0.80	0.80
Available P (%)	0.45	0.45	0.40	0.40
TSAA (% digestible)	0.91	0.91	0.76	0.76
Lysine (% digestible)	1.22	1.22	1.05	1.05
Na (%)	0.22	0.22	0.22	0.22

[1]DDGS = distillers dried grains with solubles.

[2]The vitamin and mineral premix contained (per kg of diet): retinyl acetate, 2,654 μg; cholecalciferol, 110 μg; DL-α-tocopherol acetate, 9.9 mg; menadione, 0.9 mg; vitamin B_{12}, 0.01 mg; folic acid, 0.6 μg; choline, 379 mg; D-pantothenic acid, 8.8 mg; riboflavin, 5.0 mg; niacin, 33 mg; thiamin, 1.0 mg; D-biotin, 0.1 mg; pyridoxine, 0.9 mg; ethoxyquin, 28 mg; manganese, 55 mg; zinc, 50 mg; iron, 28 mg; copper, 4 mg; iodine, 0.5 mg; selenium, 0.1 mg.

[3]Provided 60 g of salinomycin sodium/907.2 kg of diet to prevent intestinal coccidia from developing.

length, 85 cm in width, and 68.5 cm in depth) and later transferred to rubber containers (142 cm in length, 81 cm in width, and 50.8 cm in depth) for sampling and sorting of breast and thigh muscles. At 4 h postmortem, breast (boneless and skinless) and thigh (bone-in) muscles were removed from the carcass. A total of 280 whole breasts and thighs were placed into individually labeled Ziploc bags (Ziploc brand freezer bags, S. C. Johnson & Son Inc., Racine, WI), brought to the Food Processing Plant (Department of Food Science, Nutrition, and Health Promotion, Mississippi State University), and cooled (2°C) overnight. At 24 h postmortem, each whole breast was separated into right and left halves. Within these samples, 6 breast samples (right side of carcass) per treatment within 7 replications (total of 210 breast samples) were evaluated for color and pH. Breast samples were then individually vacuum-packaged (Turbovac 320-ST-S, Inject Star of the Americas Inc., Brookfield, CT) in 15.2 × 20.3 cm, 3-mil vacuum pouches (75001815, Rebel Butcher Supply Co. Inc., Flowood, MS) and frozen (−23°C) until proximate analysis (n = 7 with 2 subsamples per treatment), cook loss (n = 7 with 4 subsamples per treatment), and shear force determinations (n = 7 with 4 subsamples per treatment) could be performed. The breasts from the same treatment within each replication from the left side of the carcasses were bagged (4 breasts per bag), vacuum-packaged (40.64 × 50.8 cm, 4-mil vacuum pouch; 75001987; Rebel Butcher Supply Co. Inc.), and frozen (−23°C) until consumer sensory acceptability tests could be performed. Thigh meat samples were placed into labeled Ziploc bags (Ziploc brand freezer bags, S. C. Johnson & Son Inc.) and frozen (−23°C) until proximate analysis, fatty acid, and lipid peroxidation [TBA reactive substances (**TBARS**)] tests could be performed.

pH Measurement

A pH meter (Accumet 61a, Fisher Scientific, Hampton, NH) was used to measure the pH of 6 breast samples (right side of the carcass) from each treatment within 7 replications (n = 7 with 6 subsamples per treatment) at 24 h postmortem by inserting a pH probe (FlexipHet SS Penetration Tip, Cole Palmer, Vernon Hills, IL) 2.5 cm below the pectoralis major muscle at approximately 2.5 cm from the top of the breast and 2.5 cm from the breast bone.

Color Measurement

Instrumental color measurements were taken for each breast sample (right side) that was used for pH measurement (n = 7 with 6 subsamples per treatment), using a chromameter (Chromameter Model CR-200, Minolta Camera Co. Ltd., Osaka, Japan) that was calibrated using a standard white calibration plate (20933026, Minolta Camera Co. Ltd.). Three measurements were taken at 3 identical locations on the surface of each breast on the medial portion of the pectoralis

major muscle. Color for each sample was expressed in terms of CIE values for lightness (L*), redness (a*), and yellowness (b*).

Cooking Loss

Four frozen breast samples from each of 5 treatments within 7 replications (n = 7 with 4 subsamples per treatment) were thawed at 2°C overnight. The thawed breasts were weighed and baked in a preheated oven at 176.7°C (JBP25DOJ2WH, General Electric, Louisville, KY) to a final internal temperature of 77°C. Internal chicken breast temperatures were determined using thermocouples and a data logger (UWTR, Omega Engineering, Samford, CT). Cooked breasts were cooled to ambient temperature (20°C), patted dry with 1 paper towel (1 ply), and reweighed. Cooking loss was reported as a percentage and calculated as (initial weight − final weight)/(initial weight) × 100.

Warner-Bratzler Shear Force Determination

Tenderness was assessed using an objective texture procedure described by Meek et al. (2000). Breasts that were used for cooking loss determinations were used for shear force determinations. Four to 6 adjacent 1 cm (width) × 1 cm (thickness) × 2 cm (length) strips were cut from the cooked breast, parallel to the direction of the muscle fibers. Each strip was sheared once, and the mean was calculated for each breast. Samples were sheared perpendicular to the muscle fibers using a Warner-Bratzler shear attachment mounted on an Instron Universal Testing Center (3300, Instron, Norwood, MA) using a 50-kg load transducer and a crosshead speed of 200 mm/min.

Proximate Analysis

Two broiler breast and 2 thigh meat samples from each of 5 treatments within the 7 replications (n = 7 with 2 subsamples per treatment) were used to measure fat, protein, and moisture percentage using a near-infrared spectrometer (FoodScan Lab Analyzer Model 78800, Foss Analytical, Eden Prairie, MN) that is AOAC-approved (AOAC, 2007). Fresh samples were stored for 1 to 2 d in a refrigerator after harvesting and then ground with a meat grinder (Cabelas PRO 450, Sidney, NE) that was fitted with a 3-mm (1/8 in.) grinder plate. Ground samples were packed tightly in a 140-mm sample cup before analysis.

Lipid Oxidation (TBA)

Thiobarbituric acid levels, expressed as milligrams of malonaldehyde per kilogram of sample, were determined using the direct chemical-extraction method described by Spanier and Traylor (1991). One broiler thigh meat sample was randomly selected from each of 5 treatments within 7 replications (n = 7 with 1 subsample per treatment) to determine lipid peroxidation changes as a function of storage (4°C) time at 1, 3, and 5 d after thawing. Thighs were thawed for 24 h at 4°C before storage and TBARS values were determined by evaluating the same thigh sample within each treatment at storage times of 1, 3, and 5 d.

Fatty Acid Profile

Fatty acid profiles were conducted on 1 broiler thigh meat sample from each of 5 treatments within 7 replications (n = 7 with 1 subsample per treatment). Lipids were extracted in ether as described by the AOAC (method 996.06; AOAC, 2000). The extracted lipids were converted to methyl esters as described by AOAC (method 969.33; AOAC, 2000) and analyzed for individual fatty acids (C14:0 and C20:4) using a gas chromatograph (3400, Varian Inc., Walnut Creek, CA) fitted with a flame ionization detector. Gas chromatograph parameters were as follows: the column temperature was 50°C for 3 min and then increased to 220°C at 4°C/min and was held for 15 min. The injector temperature was 200°C, and the detector temperature was 250°C. The flow rates of the carrier gases (hydrogen and oxygen) were 30 and 300 mL/min, respectively. Identification and quantification of individual fatty acids were performed by using a standard FAME-7 mixture (2010, Matreya Biochemicals LLC, Pleasant Gap, PA).

Sensory Analysis

Three consumer-based sensory panels (n = 55 panelists per replication) were conducted to evaluate the acceptability of chicken breast meat from broilers that that were fed diets that contained between 0 and 24% DDGS. Each panel consisted of students, staff, and faculty at Mississippi State University and panelists varied from replication to replication. Chicken breasts, which were previously frozen (<−20°C), were thawed at 2°C for 24 h before sensory testing and placed on broiler pans for even distribution of heat during cooking. Thermocouples (UWTR, Omega Engineering) were inserted in the thickest portion of each breast sample and baked to an internal temperature of 77°C. Baked breasts were cooled at room temperature for 15 min, cut into 2.5 × 2.5 × 2.5 cm cubes, and kept warm (60 to 70°C) in 8-quart chafer dishes (53042, Polarware Co., Kiel, WI) until panelists evaluated the samples. Random 3-digit numbers were assigned to identify the samples. Sample order was randomized to account for sampling order bias. Water and unsalted crackers were provided, and panelists were asked to expectorate and rinse their mouths between each sample. Each panelist was asked to evaluate 5 coded chicken breast samples, 1 sample from each treatment (0, 6, 12, 18, and 24% DDGS) for appearance, aroma, texture, flavor, and overall acceptability using a 9-point hedonic scale, in which 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely (Meilgaard et al., 2007).

Statistical Analysis

A completely randomized design with 7 replications (n = 7 with 8 samples per treatment within each replication) was used to test the effects of diet (0, 6, 12, 18, or 24% DDGS) on ultimate pH, color, cooking loss, shear force, and proximate analysis of broiler breast meat and the peroxidation (TBARS), fatty acid profile, and proximate analysis of broiler thigh meat (version 9.1, SAS Institute, Cary, NC). In addition, a factorial structure was used in the TBARS analysis because samples were analyzed over time for each diet. When significant differences ($P < 0.05$) existed among treatments, the Fisher's least significant difference test was used to separate treatment means. A randomized complete block design (replications and panelists as blocks) with 3 replications was used to test the treatment effects ($P < 0.05$) of diet on the overall acceptability and the acceptability of texture, aroma, and flavor of breast meat (Meilgaard et al., 2007). When significant differences ($P < 0.05$) existed among treatments, the Fisher's least significant difference test was used to separate treatment means.

RESULTS AND DISCUSSION

pH and Color

Breast meat from broilers that were fed 12 to 24% DDGS had higher ($P < 0.05$) average ultimate pHs than the control treatment, and the 18 and 24% DDGS-fed treatments had breast meat with a higher ($P < 0.05$) average pH than those from the 6% DDGS treatment (Table 2). This reveals that feeding DDGS to the broilers caused the breast meat to be less acidic, which generally indicates higher quality meat. However, all breast meat from the control (0% DDGS) treatment had high water-holding capacity, good color, and tender meat (Table 2). Therefore, differences in pH that were observed in this study were not indicative of differences with respect to meat quality. Also, average values for pH were characteristic of normal broiler breast meat at 24 h postmortem (5.8 to 6.2; Van Laack et al., 2000; Woelfel et al., 2002) for all treatments. In addition, pH had a slight indirect relationship with L* and b*, but breast L* and b* values were characteristic of normal meat with no inherent quality problems.

No differences existed ($P > 0.05$) among breast meat that was harvested from DDGS-fed broilers with respect to L*, a*, and b* (lightness, redness, yellowness; Table 2). The L*, a*, and b* values for all treatments were characteristic of normal broiler breast meat (L* < 55) at 24 h postmortem (Van Laack et al., 2000; Woelfel et al., 2002; Battula et al., 2008; Schilling et al., 2008; Corzo et al., 2009).

Cooking Loss and Shear Force

No differences existed ($P > 0.05$) among breast meat with respect to cooking loss from broilers that were fed different percentages of DDGS (Table 2). In addition, there was more variation within treatments with respect to cooking loss than among treatments, and values were very similar (19 to 21%) to previously reported results in which a similar cooking method was used (Corzo et al., 2009). Breast meat from the control treatment had a lower ($P < 0.05$) average shear force value than breast meat from broilers that were fed the 18 and 24% DDGS treatments, and breast meat from the 6% DDGS treatment had a lower ($P < 0.05$) shear force value than the breast meat from the 24% DDGS treatment (Table 2). However, all individual samples had shear forces values less than 30 N, which indicates very tender meat that would be highly acceptable to consumers (Schilling et al., 2003). Therefore, the slight differences in shear force are not likely to have a practical significance with regard to meat quality and sensory acceptability.

Proximate Analysis

No differences existed ($P > 0.05$) among thigh meat with respect to proximate analysis from broilers that were fed various levels of DDGS (Table 3). For fat and moisture content of thighs, *P*-values were 0.97 and 0.99, which demonstrates that total fat and moisture were not only statistically insignificant but were also practically identical with low ranges and standard errors. For breast meat, no differences existed ($P > 0.05$) among

Table 2. pH and cooked color (24 h), cooking loss, and shear force values of chicken breast meat from broilers that were fed different concentrations of distillers dried grains with solubles (DDGS)[1]

Treatment	pH (24 h)	L* (lightness)	a* (redness)	b* (yellowness)	Cooking loss (%)	Shear force[2] (N)
Control (0% DDGS)	5.81^{c}	53.8	2.4	3.2	19.5	15.1^{c}
6% DDGS	5.92^{b}	53.5	2.4	2.8	20.6	15.5^{bc}
12% DDGS	5.96^{ab}	53.3	2.2	2.7	20.6	15.8^{abc}
18% DDGS	5.99^{a}	53.2	2.6	2.5	20.0	16.1^{ab}
24% DDGS	5.99^{a}	52.9	2.7	2.4	20.1	16.3^{a}
P-value	<0.0001	0.50	0.33	0.25	0.49	0.018
SEM	0.02	0.37	0.17	0.27	0.50	0.27

$^{a–c}$Means with different superscripts within each column are significantly different ($P < 0.05$).

[1]n = 7 (per treatment).

[2]n = maximum peak force (N) required.

Table 3. Proximate composition of chicken thigh and breast meat from broilers that were fed diets with different concentrations of distillers dried grains with solubles (DDGS)[1]

	Thigh			Breast		
Treatment	Fat (%)	Protein (%)	Moisture (%)	Fat (%)	Protein (%)	Moisture (%)
Control (0% DDGS)	7.2	19.6	71.5	2.8	23.1	73.2
6% DDGS	7.5	19.2	71.2	2.2	23.1	73.5
12% DDGS	7.5	19.4	71.3	2.3	23.1	73.6
18% DDGS	7.4	19.3	71.4	2.2	22.8	73.6
24% DDGS	7.4	19.1	71.3	2.3	23.4	73.4
P-value	0.99	0.40	0.97	0.07	0.20	0.60
SEM	0.39	0.14	0.31	0.17	0.17	0.20

[1]n = 7 (per treatment).

DDGS treatments with respect to fat, protein, and moisture (Table 3). Results for proximate analysis indicate that broilers can be fed between 0 and 24% DDGS, if diets are formulated appropriately, without affecting the protein and fat percentage of the muscle tissue.

Fatty Acid Composition

Four out of the 16 fatty acids that were detected in broiler thighs differed ($P < 0.05$) in proportion among DDGS treatments (Table 4). In addition, 5 more fatty acids were different at $P < 0.10$. Thighs from the control treatment had a higher proportion of palmitic acid (C16:0) than thigh meat from the 18 and 24% DDGS treatments and also had a higher ($P < 0.05$) concentration of oleic acid (C18:1) than thigh meat from all DDGS treatments (Table 4). The most significant variation among treatments was observed with linoleic acid (C18:2). Feeding DDGS increased ($P < 0.0001$) the concentration of linoleic acid in thigh meat when compared with the control, and the 24% DDGS treatment had more linoleic acid than the control, 6, and 12% DDGS treatments (Table 4). Feeding DDGS also had a tendency to increase ($P < 0.10$) linolenic acid (C18:3n-9) when compared with the control. In addition, the 0% DDGS treatment had more ($P < 0.05$) saturated fat than the 12, 18, and 24% treatments and had more monounsaturated fatty acids than all DDGS treatments. Polyunsaturated fatty acid percentage increased ($P < 0.05$) as DDGS percentage increased. All DDGS treatments had more ($P < 0.05$) polyunsaturated fatty acids than the control. In addition, the 18 and 24% treatments had more unsaturated fatty acids than the 6% DDGS treatment. These results are similar to those of Corzo et al. (2009), who reported an increase in linoleic acid and total polyunsaturated fatty acids in thigh meat from broilers that were fed 8% DDGS in comparison to a 0% DDGS treatment.

It is evident from literature that fatty acid composition of the feed is the most important determinant of the fatty acid composition in the resulting broiler breast and thigh meat (Cortinas et al., 2004). Therefore, current research reveals that increasing DDGS concentration will affect fatty acid composition due to

Table 4. Fatty acid profile of chicken thigh meat from broilers that were fed diets with different concentrations of distillers dried grains with solubles (DDGS)[1]

Fatty acid	Control (0% DDGS)	6% DDGS	12% DDGS	18% DDGS	24% DDGS	*P*-value	SEM
Myristic (C14:0)	0.66	0.65	0.58	0.60	0.59	0.61	0.04
Pentadecanoic (15:0)	0.12	0.15	0.11	0.17	0.12	0.41	0.02
Palmitic (C16:0)	24.2^{a}	23.1^{ab}	22.7^{bc}	22.0^{c}	21.7^{c}	0.0005	0.38
Heptadecanoic (C17:0)	0.16	0.18	0.16	0.18	0.18	0.56	0.02
Stearic (C18:0)	7.29^{abc}	7.57^{a}	6.70^{bc}	7.42^{ab}	6.48^{c}	0.04	0.28
Arachidic (C20:0)	0.10	0.12	0.10	0.15	0.12	0.21	0.02
Myristoleic (C14:1)	0.15	0.13	0.17	0.12	0.14	0.43	0.02
Palmitoleic (C16:1)	6.29	5.46	5.74	5.1	5.31	0.054	0.28
Oleic (C18:1 *cis*)	35.9^{a}	33.9^{b}	34.1^{b}	33.1^{b}	33.7^{b}	0.0032	0.46
Linoleic (C18:2 *cis*)	21.2^{d}	24.2^{c}	25.7^{bc}	26.5^{ab}	27.9^{a}	<0.0001	0.64
Linolenic (C18:3n-6)	0.39	0.48	0.38	0.62	0.29	0.094	0.08
Linolenic (C18:3n-9)	0.85	0.93	0.97	0.96	0.97	0.077	0.03
Eicosenoic (C20:1)	0.21	0.19	0.17	0.20	0.19	0.42	0.01
Eicosadienoic (C20:2)	0.24	0.20	0.26	0.29	0.26	0.55	0.04
Eicosatrienoic (C20:3n-8)	0.40	0.39	0.32	0.38	0.33	0.087	0.02
Arachidonic (C20:4)	1.90	2.24	1.83	2.44	1.75	0.053	0.19
Saturated (%)	32.5^{a}	31.6^{ab}	30.4^{bc}	30.5^{bc}	29.2^{c}	0.0001	0.44
Monounsaturated (%)	42.6^{a}	39.7^{b}	40.2^{b}	38.4^{b}	39.3^{b}	0.0023	0.67
Polyunsaturated (%)	24.9^{c}	28.5^{b}	29.4^{ab}	31.2^{a}	31.5^{a}	<0.0001	0.80

[a–d]Means with different superscripts within each row are significantly different ($P < 0.05$).

[1]Values are expressed as a percentage of the total fatty acid concentration because total fat percentage did not differ among treatments.

increased concentrations of polyunsaturated fatty acids in the feed. Because an increased concentration of polyunsaturated fatty acids is an indicator of increased susceptibility to oxidation (Faustman, 1994), increasing the concentration of DDGS in feed could potentially make thigh meat more susceptible to oxidation.

Because linoleic acid concentrations increased in thigh meat as concentration of DDGS increased in the broiler diets (Table 4), there may be potential health benefits to feeding DDGS to broilers. Linoleic acid is an n-3 essential fatty acid that is generally considered healthier than saturated fatty acids that were decreased as DDGS feed concentration increased. Linoleic acid is important to human health because it can be converted to eicosapentaenioc and docosapentaenoic acids (McClements and Decker, 2008), which are important in the prevention of platelet aggregation and cognitive reasoning. However, because most Western diets have an excess of linoleic acid in comparison to n-6 fatty acids such as linolenic acid (McClements and Decker, 2008), it is not clear whether there would truly be an enhanced health benefit from feeding DDGS.

Lipid Oxidation (TBARS)

No differences existed ($P > 0.05$) among treatments with respect to TBARS after 1 d of storage (Figure 1). After 3 d of storage, the 18% DDGS treatment had higher TBARS values ($P < 0.05$) than all of the other treatments. All TBARS values were relatively low at d 3, indicating very slight oxidation. Thighs from the 18 and 24% DDGS treatments were more oxidized ($P < 0.05$) than thighs from the 0 and 6% DDGS treatments after 5 d of storage (Figure 1). However, the 6 and 12% DDGS treatments were not different from the control with respect to TBARS levels. These increases in oxidation are likely due to the increases in linoleic acid and total polyunsaturated fatty acids that are seen in broilers that are fed 18 and 24% DDGS. Results are similar to those of Corzo et al. (2009), but slight increases in oxidation were seen over time in thighs from broilers that were fed 8% DDGS in comparison to the control. Differences may have occurred due to slightly higher initial levels of TBARS and a larger sample size in the referenced study when compared with the current study. Results for TBARS values in the current study were also similar to those reported by Ang and Lyon (1990) for thigh meat that was stored for 0 and 1 d (2°C) but slightly lower than those for thigh meat that was stored for 2 to 5 d. It is interesting that no differences were seen in oxidation between the control and 6 and 12% DDGS treatments because there were also higher concentrations of polyunsaturated fatty acids in these treatments when compared with the control. This may have occurred because there were not enough differences in fatty acid content for differences in oxidation to be noticed after 5 d of storage. These results reveal that broilers can be fed 0 to 12% DDGS without negatively affecting the quality and shelf-life of thigh meat. In addition, inclusion of 12% DDGS increases the amount of essential fatty acids (due to increases in linoleic acid), which could potentially add nutritional value to thigh and breast meat. To optimize thigh meat quality, 0, 6, or 12% DDGS could be used in feed, but levels of 18 and 24% DDGS may lead to potential oxidation in thigh meat. However, if differences in oxidation at storage times of 5 d or longer were not a concern, increasing DDGS concentration would maximize nutritional benefits because it increases the concentrations of linoleic acid and other polyunsaturated fatty acids that are essential fatty acids in human nutrition.

Correlations were calculated to determine the relationship between fatty acid content and TBARS values. There was a strong correlation between TBARS values at 5 d of refrigerated storage and polyunsaturated fatty acid (r = 0.80) and linoleic acid (r = 0.77) concentrations, respectively. Correlations were not as high as expected because TBARS values were numerically higher for the 18% DDGS treatment in comparison to the 24% DDGS treatment and polyunsaturated fatty acid composition was numerically higher in the 24% DDGS treatment in comparison to the 18% DDGS treatment. Correlations were minimal (0.70 < r) between other fatty acid concentrations and TBARS at refrigerated storage times of 1, 3, and 5 d.

Consumer Acceptability

No differences existed ($P > 0.05$) in the acceptability (appearance, aroma, flavor, texture, and overall) of

Table 5. Consumer acceptability of chicken breast meat from broilers that were fed diets with different concentrations of distillers dried grains with solubles (DDGS)[1,2]

Treatment	Appearance	Aroma	Flavor	Texture	Overall acceptability
Control (0% DDGS)	6.6	6.3	6.2	6.8	6.4
6% DDGS	6.7	6.1	6.2	6.6	6.4
12% DDGS	6.6	6.3	6.2	6.7	6.3
18% DDGS	6.5	6.3	6.2	6.5	6.2
24% DDGS	6.7	6.2	6.3	6.7	6.4
P-value	0.44	0.30	0.88	0.57	0.58
SEM	0.10	0.10	0.12	0.10	0.11

[1]Hedonic scale was based on a 9-point scale: 1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely.

[2]n = 164.

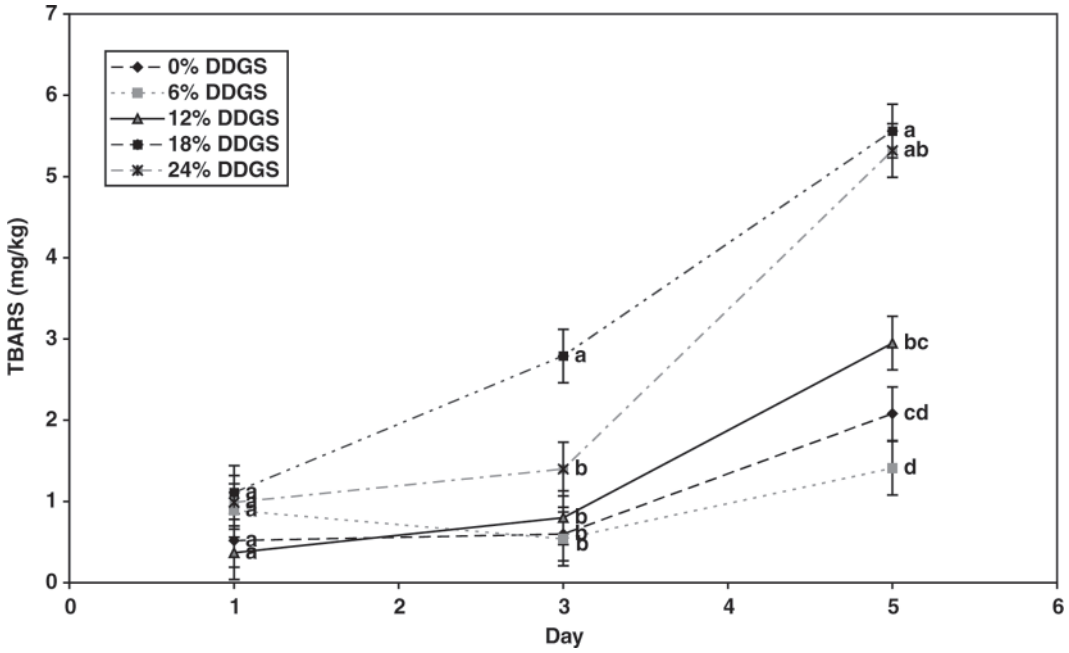

Figure 1. Thiobarbituric acid reactive substances (TBARS) values (mg/kg) of chicken thighs (n = 7) from broilers fed diets with or without distillers dried grains with soluble (DDGS). For each treatment time (d), means with different letters are significantly different ($P < 0.05$).

broiler breast from broilers that were fed varying concentrations of DDGS (Table 5). On average, all scores ranged between like slightly and like moderately for all treatments with respect to appearance, aroma, flavor, texture, and overall acceptability (Table 5). These results are similar to those of Corzo et al. (2009), with the exception that the control treatment was slightly preferred over breast meat from the 8% DDGS treatment and the average scores for all treatments were slightly higher than the scores in the current study. Differences may have occurred because the consumer panels for the 2 studies were comprised of different panelists. Results from the current study indicate that feeding birds DDGS in the range of 0 to 24% will have minimal effects on the acceptability of broiler breast meat. In addition, acceptability scores for breast meat from all treatments were similar to those that have been reported in previous studies (Schilling et al., 2003; Battula et al., 2008; Corzo et al., 2009) when a 9-point hedonic scale is used.

In conclusion, results from this research indicate that feeding broilers 0 to 12% DDGS will not affect the quality of broiler breast and thigh meat. However, feeding greater than 12% DDGS in broiler diets results in increased polyunsaturated fatty acids in broiler thigh meat, which leads to increased oxidation over storage time but has no effect on instrumental or sensory quality of broiler breast meat.

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