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Effects of fermented wheat-rice distillers dried grains with solubles on meat quality and amino acid profile in broilers

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Abstract

The aim of this experiment was to evaluate the effects of replacing distillers dried grains with solubles (DDGS) with fermented DDGS (FDDGS) on meat quality and serum amino acid profiles in Chinese yellow broilers. Forty-eight 42-day-old male Chinese yellow broilers were randomly allotted to the treatments. Each treatment was replicated six times with four birds per replicate. Both groups received a basal corn-soybean diet that was supplemented with either 20% DDGS or 20% FDDGS. Broilers were euthanized at 70 days old. The right half of each breast was evaluated for meat quality. Both breast and thigh meats were evaluated for proximate and fatty acid composition. Serum from blood samples was analysed to quantify relative amounts of free amino acids. Breast meat from broilers supplemented with FDDGS had a lower pH and less drip loss than those supplemented with DDGS (P <0.05). No differences were detected between treatments in the proximate composition of breast and thigh meat (P >0.05). Myristic acid (C14:0) concentration of thigh muscles was reduced for broilers supplemented with FDDGS compared with those supplemented with DDGS ($P<0.05$). Concentrations of lysine, taurine, alpha-aminoadipic acid, glycine, and 3-methylhistidine in serum were all lower for broilers supplemented with FDDGS than for those supplemented with DDGS ($P<0.05$). Meanwhile, the serum phosphoserine concentration of the FFDS-supplemented broilers was greater than those supplemented with DDGS ($P<0.05$). In conclusion, replacing 20% DDGS with a like amount of FDDGS can be recommended for diets of growing broiler chickens.

Keywords: fatty acids, meat quality, shear force
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Introduction

As ethanol production has expanded in recent years, the availability of DDGS as a feedstuff for poultry diets has increased. Owing to the high percentage of lignocellulose and low quality of protein (Barekatain *et al.*, 2013), effective utilization of DDGS remains an elusive problem in animal production. For poultry, DDGS can be included as 10% to 15% of their diet without reducing product quality (Shim *et al.,* 2011). However, production efficiency was shown to decrease when the concentration of DDGS exceeded 18% (Abudabos *et al.*, 2017b). Schilling *et al.* (2010) observed that broilers whose diets were supplemented with 18% and 24% DDGS produced breast meat with higher pH and shear force compared with a control treatment.

Palmitic acid, oleic acid and linoleic acid are the predominant fatty acids in DDGS, comprising as much as 21.05%, 22.12%, and 49.92% of the total fatty acid content, respectively (Abudabos et al., 2017a). The evaluated linoleic acid of DDGS improved meat quality by increasing the proportion of polyunsaturated fatty acids (PUFAs) (Min *et al.,* 2015; Jiang *et al.,* 2014). However, PUFAs are vulnerable to lipid peroxidation (Stein & Shurson, 2009). Feeding DDGS that contain oxidized lipids may induce oxidative stress, alter immune function and, thus, negatively affect animal growth performance.

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Solid-state fermentation has been utilized to improve the nutritional value of agricultural by-products. Fermentation loosens the structure of lignocellulose and makes the nutrients in DDGS more accessible to animals. Microorganisms also add nutrients, such as small peptides, to the substrate, which might be present at inadequate levels in the unfermented samples. Studies in the authors' laboratory showed that after fermentation, crude protein content was elevated and the crude fibre content of DDGS decreased (data not published). The improved nutritional value as a result of fermentation has already been demonstrated. However, it is unclear whether substituting FDDGS for DDGS can relieve negative effects on the performance and meat quality that result from supplementation of broilers with high levels of DDGS. Therefore, the present study was conducted to investigate the effects of replacing DDGS with FDDGS at high inclusion levels on growth performance, meat quality, and serum amino acid profile in broilers.

Materials and Methods

The experimental design and procedures in this study were reviewed and approved by the Animal Care and Use Committee of the College of Life Sciences and Environment, Hengyang Normal University.

A total of 48 Chinese yellow male broilers, with an initial bodyweight of 1.26 ± 0.02 kg, were randomly assigned to two treatments. Each treatment was replicated six times with four birds per replicate. Two diets were evaluated and each contained 80% of a basal diet, which was supplemented with 20% of either FDDGS or DDGS. The basal diet (Table 1) was formulated to meet NRC (1994) nutrient recommendations. The DDGS was a by-product of beer production and was provided by the Yanjing Beer Company (Yanjing, Hengyang, China). Fermentation of the DDGS was done in the authors' laboratory using *Aspergillus niger*, *Saccharomyces cerevisiae*, and *Bacillus subtilis*. The gross energy, protein, fat, crude fibre, and ash contents of the FDDGS were 4902 kcal/kg, 32.41%, 4.15%, 7.21% and 3.47% respectively. The corresponding proximate composition of the DDGS was 5180 kcal/kg gross energy, 24.90% protein, 3.92% fat, 14.67% crude fibre, and 3.99% ash. The amino acid compositions of the DDGS and FDDGS are shown in Table 2. The ammonia concentration in DDGS was 3.70%, whereas in the FDDGS it was 0.99%. Birds were housed in wire-floored suspended cages, and consumed feed and water on an ad libitum basis. The experiment was performed between April and May and lasted 28 days. Housing conditions were controlled by a natural ventilation system and there were two fans in the room. Natural lighting was applied during the experiment.

Bodyweight was recorded every week. Feed consumption could not be measured because of an indeterminate amount of feed wastage. At day 28, blood samples were collected from the wing vein and centrifuged (2000 x g, 15 min) at room temperature. The serum was then harvested and stored at -80 °C until analysis. At the end of the four-week feeding period, six broilers from each treatment were randomly selected and euthanized by cervical dislocation. Abdominal fat, crureus, breast muscles, oesophagus, glandular stomach, muscular stomach, duodenum, jejunum, ileum, cecum, colorectum, bursal, spleen, and liver were separated and weighed. Breast and thigh muscles were sampled from the right side of carcass. Samples from the breast and thigh muscles were stored at -4 °C for subsequent measurement of shear force. Additional samples of the breast and thigh muscles were stored at -80 °C until analysis.

The colour of the breast muscle was evaluated subjectively on a scale from 1 to 5 (1 = pale pinkish grey to white, and 5 = dark purplish red) using a standard colorimetric board (Minolta, Osaka, Japan). A hand-held pH meter (Russell CD700, Russell pH Limited, Paisley, Scotland) was used to measure the pH of breast samples at 45 min post mortem. Drip loss of breast was determined by a suspension method. The breast muscle was weighed and placed in a plastic bag, suspended at 4 °C in a cooler for 24 hours and reweighed, and the percentage drip loss was calculated:

$$\%\ \text{drip loss} = \frac{\text{final weight} - \text{initial weight}}{\text{initial weight}} \text{x}100$$

The fresh breasts were weighed and baked in a steamer to a final internal temperature of 77 °C. The cooked breasts were cooled to ambient temperature, and reweighed. Cooking loss was calculated as a percentage of the weight that was lost based on the pre-cooking weight of breast. Breasts that were used to determine cooking loss were then used to calculate shear force. To measure the firmness, breasts were cut into squares (20 x 10 x 10 mm) and then subjected to the measurement of shear force using a digital tenderness meter (C-LM3B, Northeast Agricultural University, Harbin, China). Three shear force values were recorded for each bird and averaged.

Table 1 Ingredients contained in the basal diet for broilers on as-fed basis, and its calculated nutrient content

Ingredients, %	Basal Diet
Corn	58.75
Soya bean meal 43 % CP	26.40
Extruded full-fat soybean	9.30
Soybean oil	1.35
Limestone	0.90
Dicalcium phosphate	1.96
Premix[1]	1.00
Salt	0.34
Calculated values	
ME, kcal/kg	2950
CF, %	2.30
Crude fat, %	5.40
CP, %	19.50
Ca, %	0.85
P, %	0.67
Digestible P, %	0.45
Salt, %	0.37
Lys, %	1.06
Met+Cys, %	0.70
Thr, %	0.81
Trp, %	0.24

[1]Vitamin A as retinyl acetate: 8065 IU; vitamin D_3 as cholecalciferol: 1580 IU; vitamin E as DL-alpha tocopheryl acetate: 15 IU; riboflavin: 7.8 mg; vitamin B_{12}: 16 µg; D-pantothenic acid as D-calcium pantothenate: 12.8 mg; niacin: 75 mg; folic acid: 1.62 mg; biotin: 0.27 mg; choline chloride: 509 mg; copper as copper sulfate: 12 mg; iron as ferrous sulfate: 60 mg; iodine as ethylenediamine dihydriodide: 2.25 mg; manganese as manganese sulfate: 80 mg; selenium as sodium selenite: 0.15 mg; and zinc as zinc sulfate: 90 mg

Table 2 Amino acid concentrations for wheat-rice-based distillers dried grains with solubles and fermented distillers dried grains with solubles, indicated as standardized ileal digestible amino acids

Amino acid	Fermented distillers dried grains with solubles, %	Distillers dried grains with solubles, %
Alanine	2.02	1.80
Arginine	2.22	1.45
Aspartic acid	2.94	2.75
Cysteine	0.59	0.44
Glutamic acid	7.32	4.77
Glycine	1.54	1.46
Histidine	0.84	0.63
Isoleucine	1.57	1.38
Leucine	3.14	2.49
Lysine	1.62	1.27
Methionine	0.55	0.66
Phenylalanine	1.73	0.98
Proline	3.04	1.66
Serine	1.78	1.44
Threonine	1.39	1.23
Tyrosine	0.35	0.65
Valine	2.14	1.71

Fresh meat samples were freeze-dried and then ground. Lipid concentrations of muscles were analysed by the Soxhlet extraction procedure using petroleum ether as the extraction agent (Soxhlet method 991.36) (AOAC, 2006). Crude protein concentrations of muscles were determined as the nitrogen content multiplied by 6.25 (method 968.06) (AOAC, 2006), using a CNS-200 carbon, nitrogen and sulphur analyser (LECO Corporation, St. Joseph, Missouri, USA). Fatty acid composition of the tissues was determined as follows. Briefly, total lipids were extracted using chloroform: methanol (2: 1, v/v) as extraction reagent. The fatty acid methyl esters (FAMEs) were prepared using a mixture of boron-trifluoride, hexane, and methanol (35: 20: 45 v/v). FAME profiles were determined by Agilent 7890A gas chromatography equipped with SP-2560 column (100 m x 250 μm x 0.2 μm) (Agilent Technologies Inc., Santa Rosa, CA). The gas chromatography conditions were as follows. The column oven temperature was set at 45 °C for 4 min, raised to 175 °C at a rate of 13 °C /min, held at 175 °C for 27 min, increased from 175 °C to 215 °C at a rate of 4 °C /min, and held at 215 °C for 35 min. The injector and detector temperatures were maintained at 250 °C. The carrier gas (hydrogen) flow rate was 30 mL/min. By comparing the FAME profile of the samples with those of FAME standards (Sigma Chemicals Co., St. Louis, MO), the fatty acid percentages were calculated relative to the total fatty acid content. Serum amino acid concentrations were analysed using oxidation analysis method on an Applied Biosystems 3200Q TRAP LC/MS/MS system equipped with RP-C18 column (150 mm length, 4.6 mm diameter, 5 mm particle size). Amino acid and fatty acid composition were tested in the Subtropical Institute of Chinese Academy of Sciences.

Treatment effects were determined by one-way analysis of variance using PROC GLM of SAS version 8.2 (SAS Inst. Inc., Cary, NC). Differences between mean values were evaluated using Tukey test at the level of $P < 0.05$.

Results and Discussion

No significant difference was noted in the average daily gain between FDDGS and DDGS groups ($P > 0.05$) (Table 3). Corn DDGS is widely used in livestock production. It has been shown that adding 30% corn DDGS to finisher diets has no negative effect on the performance of Chinese yellow broilers (Ruan *et al*., 2017). In the present study, adding 20% wheat and rice-based DDGS as a supplement was not appropriate because broilers from both groups lost similar amounts of weight during the first week (result not shown). However, adaptation to these diets may explain this result, since subsequently the birds regained the lost weight. Based on digestible amino acid content, it has been reported that 20% DDGS from corn could be used in broiler diets (Wang *et al.,* 2007), and 25% DDGS has been found acceptable as well (Shim *et al*., 2011). Ten per cent DDGS has traditionally been the recommended limit for feeding broiler chickens during the grower period (Stein, 2007). Performance may be depressed at early age. However, subsequently the chicks have been able to tolerate this level of DDGS supplementation (Abudabos *et al.,* 2017b). Unlike in the present study, use of fermented meal has been shown to improve the performance of broiler chickens compared with unfermented meal (Jazi *et al.,* 2017; Dei *et al.,* 2008).

Table 3 Growth of broilers fed diets supplemented with either 20% fermented distillers dried grains with solubles or 20% fermented distillers dried grains with solubles from 42 to 70 days old

	Supplement[1]			
	FDDGS	DDGS	SE	*P*-value
Bodyweight, d 42, kg	1.25	1.27	0.01	0.194
Bodyweight, d 70, kg	1.35	1.44	0.04	0.274
Average daily gain, g/d	14.00	12.84	1.58	0.726

[1]FDDGS: fermented distillers dried grains with solubles, DDGS: distillers dried grains with solubles

No differences existed between FDDGS and DDGS treatments in the subjective incarnadine score, cooking loss, shear force, protein and fat content of breasts and thighs ($P > 0.05$) (Table 4). Breast muscle from broilers that were fed FDDGS had lower pH and lower percentage of drip loss than those from the DDGS treatment ($P < 0.05$). Feeding FDDGS to Chinese yellow broilers caused breast meat to be less acidic, which generally indicates higher quality meat. No comparable study was found that showed how FDDGS affects the pH of chicken meat. Schilling *et al.* (2010) found that feeding 12%–24% corn DDGS resulted in higher average at pH 24 h than in an unsupplemented control and 6% corn DDGS treatment. However, other reports have shown that the addition of corn DDGS to a ration did not affect the pH value of breast meat in

broilers (Ruan *et al*., 2017; Min *et al*., 2012). The increased pH may be related to altered glucose utilization in birds fed DDGS resulting in glycogen depletion. Previous reports have shown drip loss to be decreased after broilers consume DDGS (Min et al., 2012; Schilling et al., 2010). However, this result has not been entirely consistent across studies (Ruan *et al*., 2017). The present results confirm the finding that FDDGS can improve the water-holding capacity (WHC). It is well known that most water in the cell is held in myofibrils and that most water is retained (steric) by capillary forces generated by the arrangement of thick and thin filaments in the myofibril (Huff-Lonergan & Lonergan, 2005). In addition, the decreased number of muscle fibres (Mazzoni *et al.,* 2015) and increased fat content are likely to play a significant role in the reduction of WHC. As fat content of breast muscle was not affected by supplementation with FDDGS, the reason for greater WHC ability in this group may be ascribed to differences in the muscle fibres, but this needs further study.

Table 4 Quality of meat from broilers supplemented with either 20% fermented distillers dried grains with solubles or 20% fermented distillers dried grains with solubles from 42 to 70 days old

	Supplement[1]			
Quality indicator	FDDGS	DDGS	SE	*P*-value
Subjective incarnadine score	1.80	2.25	0.16	0.197
Ph	5.30	6.00	0.14	0.046
Drip loss, %	0.96	1.48	0.11	0.048
Cooking loss, %	26.72	26.23	0.89	0.794
Shear force, kg of force/cm^2	3.69	3.88	0.21	0.659
Protein content of thigh muscles, %	0.46	0.52	0.02	0.273
Protein content of breast muscles, %	0.62	0.58	0.01	0.324
Crude fat content of thigh muscles,	7.92	8.91	0.32	0.082
Crude fat content of breast muscles, %	3.32	3.54	0.22	0.560

[1]FDDGS: fermented distillers dried grains with solubles, DDGS: distillers dried grains with solubles

Only one of 15 fatty acids found in broiler thighs was significantly different between treatments (Table 5). Thighs from birds that were supplemented with FDDGS had less myristic acid (C14:0) than those from broilers that had been supplemented with DDGS ($P<0.05$). In addition, birds that consumed FDDGS tended (P <0.10) to have less elaidic acid (C18:1n9T) compared with thighs from broilers that had been supplemented with DDGS. There were no significant differences between treatments in fatty acid composition in breast muscle (Table 6). Fatty acid composition of the feed is the most important determinant of the fatty acid composition in the resulting meat (Su *et al*., 2013). Jiang *et al.* (2014) found that the proportion of monounsaturated fatty acid in thigh meat decreased and the proportion of PUFA increased when the diet was supplemented with 15% DDGS. An increased proportion of PUFA is may indicate increased susceptibility to oxidation. Thus, increasing the level of DDGS in the diets could make thigh meat more susceptible to oxidation. Including DDGS at 200g/kg in the diet has been shown to reduce the concentrations of stearic and behenic acids in thigh meat (Shim *et al*., 2018).

The effects of FDDGS supplementation on relative organ weights of broilers are shown in Table 7. Percentages of colorectum and large intestine were decreased in birds supplemented with FDDGS compared with those supplemented with DDGS (P <0.05). Percentages of abdominal fat and oesophagus tended to be lower and percentages of the duodenum, spleen, and the small intestine tended to be greater in broilers supplemented with FDDGS compared with those supplemented with DDGS (P <0.10). No differences between the treatments were detected for the percentages of crureus, breast muscles, glandular stomach, muscular stomach, jejunum, ileum, cecum, bursae and livers of broilers that were fed different diets (P >0.10).

Feeding FDDGS decreased ($P<0.05$) the concentrations of lysine, taurine, alpha-aminoadipic acid, glycine, and 3-Methylhistidine in the serum when compared with broilers that had been supplemented with DDGS (Table 8). Meanwhile, serum concentration of phosphoserine was greater for broiler Supplemented with FDDGS compared with DDGS ($P<0.05$). However, was no differences were observed between treatments in serum concentration of histidine, threonine, valine, methionine, isoleucine, leucine, phenylalanine, arginine, urea, aspartic acid, serine, glutamic acid, sarcosine, alanine,β- alanine, citrulline, α-

aminobutyric acid, cysteine, cystathionine, tyrosine, β-aminoisobutyric acid, γ-aminobutyric acid, ethanolamine, hydroxylysine, ornithine, 1-methylhistidine, carnosine, anserine, proline, and hydroxyproline (*P* >0.05).

Table 5 Fatty acid profile of meat from thighs of broilers supplemented with either 20% fermented distillers dried grains with solubles or 20% fermented distillers dried grains with solubles from 42 to 70 days old

	Supplement[1]			
Fatty acid, %	FDDGS	DDGS	SE	*P*-value
Myristic (C14:0)	0.68	0.75	0.01	0.032
Palmitic (C16:0)	23.42	24.59	0.52	0.299
Heptadecanoic (C17:0)	0.29	0.30	0.01	0.765
Stearic (C18:0)	9.11	9.09	0.25	0.965
Arachidic (C20:0)	0.12	0.09	0.01	0.131
Palmitoleic (C16:1)	3.46	3.41	0.16	0.868
Elaidic (C18:1n9T)	0.16	0.19	0.01	0.095
Oleic (C18:1n9C)	37.06	37.25	0.88	0.916
Eicosenoic (C20:1 n9)	0.53	0.47	0.02	0.191
Linoleic (C18:2n6C)	23.57	22.17	0.98	0.498
γ-Linolenic (C18:3n6)	0.22	0.21	0.02	0.779
Homo-γ-Linolenic (C20:3n6)	0.26	0.31	0.03	0.401
Arachidonic (C20:4n6)	0.14	0.13	0.02	0.672
α-Linolenic (C18:3n3)	0.75	0.87	0.04	0.195
Docosahexaenoic (C22:6n3)	0.22	0.21	0.02	0.663

[1]FDDGS: fermented distillers dried grains with solubles, DDGS: distillers dried grains with solubles

Table 6 Fatty acid profile of meat from the breast of broilers supplemented with either 20% fermented distillers dried grains with solubles or 20% fermented distillers dried grains with solubles from 42 to 70 days old

	Supplement[1]			
Fatty acid[a], %	FDDGS	DDGS	SE	*P*-value
Myristic (C14:0)	0.58	0.64	0.02	0.182
Palmitic (C16:0)	23.33	24.05	0.36	0.384
Heptadecanoic (C17:0)	0.26	0.27	0.01	0.915
Stearic (C18:0)	9.54	10.02	0.39	0.589
Arachidic (C20:0)	0.10	0.10	0.01	0.639
Palmitoleic (C16:1)	2.70	2.75	0.27	0.942
Elaidic (C18:1n9T)	0.14	0.16	0.01	0.122
Oleic (C18:1n9C)	32.30	33.16	1.05	0.710
Eicosenoic (C20:1 n9)	0.90	0.75	0.20	0.729
Linoleic (C18:2n6C)	20.89	19.58	0.89	0.515
γ-Linolenic (C18:3n6)	0.18	0.17	0.01	0.780
Homo-γ-Linolenic (C20:3n6)	0.37	0.47	0.08	0.588
Arachidonic (C20:4n6)	7.27	5.97	0.61	0.353
α-Linolenic (C18:3n3)	0.61	0.73	0.06	0.384
Docosahexaenoic (C22:6n3)	0.80	0.68	0.14	0.691

[1]FDDGS: fermented distillers dried grains with solubles, DDGS: distillers dried grains with solubles

Table 7 Relative organ weights (%) of broilers supplemented with either 20% fermented distillers dried grains with solubles or 20% fermented distillers dried grains with solubles from 42 to 70 days old

Organ	Supplement[1]		Standard error	*P*-value
	FDDGS	DDGS		
Abdominal fat	1.62	2.29	0.14	0.052
Crureus	5.61	5.21	0.12	0.144
Breast muscles	4.72	4.90	0.29	0.763
Oesophagus	0.17	0.24	0.02	0.085
Glandular stomach	0.56	0.44	0.04	0.214
Muscular stomach	2.11	2.46	0.15	0.273
Duodenum	0.87	0.75	0.02	0.052
Jejunum	0.55	0.47	0.03	0.220
Ileum	0.47	0.46	0.02	0.812
Cecum	0.40	0.53	0.03	0.100
Colorectum	0.76	1.09	0.04	0.004
Bursal	0.10	0.10	0.01	0.872
Spleen	0.23	0.15	0.02	0.055
Liver	1.86	1.75	0.09	0.602
Small intestine	1.88	1.69	0.04	0.060
Large intestine	1.15	1.62	0.04	0.001

[1]FDDGS: fermented distiller's dried grains with solubles, DDGS: distiller's dried grains with solubles

Previously, including DDGS in the diet of broilers decreased the digestibility of crude protein in meat from broilers (Kim *et al*., 2018). Fermentation has also increased digestibility of essential amino acids and other useful nutrients (Shi *et al.,* 2015) and promoted muscle protein metabolism (Saleh *et al*., 2014). However, protein concentrations of both breast and thigh muscle were not affected by fermentation in the current study. Although the crude protein of the FDDGS was greater than that of DDGS, serum lysine content was reduced in the FDDGS supplemented group. This implies that the digestibility of amino acids was not improved by fermentation. Lysine, α-Aminoadipic acid, and phosphoserine are engaged in emotional regulation. Thus, stress behaviour might be more likely to occur in the FDDGS-supplemented group as serum lysine and α-Aminoadipic acid levels were reduced and the serum phosphoserine level was elevated in this group. These findings may be attributable to the lower fibre content of FDDGS, because previous studies have reported beneficial effects of fibre on satiety.

Table 8 Free amino acid content of serum from broilers supplemented with either 20% fermented distillers dried grains with solubles or 20% fermented distillers dried grains with solubles from 42 to 70 days old

	Supplement[1]			
Amino acid, μmol/L	FDDGS	DDGS	SE	*P*-value
Histidine	6.74	9.07	0.89	0.265
Threonine	13.07	19.82	2.12	0.184
Valine	8.03	9.03	0.78	0.572
Methionine	5.96	4.22	0.46	0.123
Isoleucine	4.41	4.50	0.26	0.874
Leucine	10.19	12.49	0.98	0.310
Phenylalanine	8.61	9.12	0.61	0.707
Lysine	12.23	19.88	1.04	0.014
Arginine	21.83	24.84	1.73	0.443
Taurine	9.59	12.96	0.30	0.002
Urea	4.95	4.14	0.56	0.522
Aspartic acid	5.61	5.23	0.51	0.738
Serine	35.12	32.53	1.74	0.510
Phosphoserine	2.29	1.72	0.10	0.035
Glutamic acid	13.83	17.76	1.16	0.162
Sarcosine	0.62	0.88	0.05	0.065
α-Aminoadipic acid	0.19	0.39	0.03	0.012
Glycine	16.88	26.10	1.34	0.018
Alanine	33.20	29.48	1.67	0.335
β-Alanine	1.73	2.11	0.18	0.357
Citrulline	1.22	1.52	0.11	0.266
α-Aminobutyric acid	1.46	1.84	0.21	0.435
Cysteine	3.65	4.41	0.40	0.410
Cystathionine	0.90	1.15	0.10	0.273
Tyrosine	13.15	11.20	1.29	0.501
β-Aminoisobutyric acid	0.91	1.05	0.11	0.554
γ-Aminobutyric acid	0.13	0.13	0.02	1.000
Ethanolamine	1.08	1.22	0.14	0.657
Hydroxylysine	0.12	0.19	0.00	0.050
Ornithine	1.25	1.37	0.07	0.470
1-Methylhistidine	6.31	4.33	1.05	0.407
3-Methylhistidine	1.33	2.24	0.15	0.032
Carnosine	2.22	3.40	0.30	0.116
Anserine	4.22	7.94	0.75	0.057
Proline	12.50	16.99	1.00	0.078
Hydroxyproline	2.65	5.30	0.59	0.076

[1]FDDGS: fermented distiller's dried grains with solubles, DDGS: distiller's dried grains with solubles

Conclusion

Relatively minor differences were observed in the performance, meat quality, relative organ weights, fatty acid profiles and amino acid profiles of the meat from broilers whose diets had been supplemented with either FDDGS or DDGS. These processed by-products of the brewing industry as sources of protein can be used as equivalent sources of protein in the diet of broiler chickens.

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Authors' contributions

CY conceived the experiment and drafted the initial manuscript. CY and XT contributed equally to this study and they jointly conducted the animal experiment and the laboratory analyses. HY, QT, JT and DB provided advice on the experiment and reviewed the manuscript. All authors read and approved the final manuscript.

Conflict of interest declaration

The authors have no conflict of interest relative to the work reported in this paper.

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