Nutrient availability of different batches of wheat distiller's dried grains with solubles for turkeys

by Pirgozliev, V.R., Whiting, I.M., Mirza, M.W. and Rose, S.P.

DOI: https://doi.org/10.1080/1745039X.2018.1435479

Pirgozliev, V.R., Whiting, I.M., Mirza, M.W. and Rose, S.P. 2018. Nutrient availability of different batches of wheat distiller's dried grains with solubles for turkeys. *Archives of Animal Nutrition*, 72(2), pp.153-161.

Nutrient availability of different batches of wheat distiller's dried grains with solubles for turkeys

Vasil Radoslavov Pirgozliev, Isobel Margaret Whiting, Muhammad Waseem Mirza, and Stephen Paul Rose

National Institute of Poultry Husbandry, Harper Adams University, Newport, Shropshire, UK

Corresponding author: V. Pirgozliev. E-mail: vpirgozliev@harper-adams.ac.uk

T: +44 (0) 1952 820280 F: +44 (0) 1952 814783

ABSTRACT

Effects of five different batches of wheat distiller's dried grains with solubles (DDGS) produced by a single production plant were used to investigate bioavailability of energy and nutrients for turkeys. The laboratory analysis of the DDGS showed variation among the different batches. Largest coefficients of variation were observed for soluble non-starch polysaccharides, oil and ash (standard deviations 12.28, 5.64 and 4.66, respectively). Birds were fed one of six mash diets. A basal diet was prepared that had major ingredients of 535 g/kg wheat and 300 g/kg soybean meal (SBM), and contained 247 g/kg CP and 12.57 MJ/kg metabolisable energy. Another five diets containing 200 g/kg of each of five experimental DDGS samples in replacement for basal diet were also mixed. Each diet was fed to eight pens with two female Premium turkeys following randomisation. The N-corrected apparent metabolisable energy (AMEn) and the nutrient retention coefficients of the pure DDGS samples were obtained using the substitution method. The AMEn of the DDGS from batch A was higher ($p = 0.048$) compared to those from batches B and C, but did not differ ($p > 0.05$)

from DDGS samples D and E. There were no differences ($p > 0.05$) in DMR, NR and FD between the DDGS samples from different batches used in this study. The AMEn of the DDGS samples correlated positively ($p < 0.05$) to the starch ($r = 0.895$), the red index of lighting (a) ($r = 0.916$) and the NSPn contents ($r = 0.940$), respectively. In general, findings from this study indicate bioavailability of energy and most nutrients to be in the range of published data with turkeys, and to vary between batches.

KEYWORDS

Wheat distillers dried grains with solubles (DDGS); turkeys; ME; digestibility

1. Introduction

The increased use of wheat for bioethanol production resulted in more available wheat distiller's dried grains with solubles (DDGS) for animal feed (Westreicher-Kristen et al. 2012). Traditionally utilised as feed ingredient for ruminants, wheat DDGS is also used in poultry diets formulations (Cozannet et al. 2010). As the price of ingredients for animal feed worldwide increases, inclusion of locally produced wheat DDGS could be more routinely used in poultry diets if there was more robust information on its nutrient availability and its variation. Compared with corn-DDGS, there is insufficient information about the nutritive value of wheat-DDGS for poultry (Opoku et al. 2015a).

There are only relatively few studies of feeding wheat DDGS to turkeys (Opoku et al. 2015b), and there is evidence that any differences that have been detected in broiler chicken studies are not directly applicable to turkeys: Kluth and Rodehutscord (2006) found different energy digestibilities of diets containing different levels of two protein concentrates when fed to broiler chickens and turkeys. Adedokun et al. (2008) compared amino acid digestibility in two samples of corn DDGS at two ages in both broiler chickens and turkeys. There were differences in total amino acid digestibility due to age between the two DDGS samples but there was a large difference in response between the broilers and turkeys. It is therefore important to directly examine the feeding value of wheat DDGS in turkeys rather than rely on data obtained with chickens.

The nutrient availability has been shown to vary substantially between DDGS samples produced by different bioethanol plants (Bandegan et al. 2009; Cozannet et al. 2010). Batch variability in metabolizable energy content and nutrient digestibility for broilers and layers within wheat DDGS samples produced by a single production plant has been reported by Whiting et al. (2015, 2017), although information on turkeys is lacking.

The main objective of the current study was to determine the N-corrected apparent metabolisable energy (AMEn) of five batches of wheat-DDGS produced at the same plant when fed to turkeys. The total tract dry matter retention (DMR), nitrogen retention (NR) and fat, measured as ether extract, digestibility (FD) coefficients were also determined. The relationship between AMEn and chemical and physical measurements of DDGS was also studied.

2. Materials and methods

2.1. Experimental Samples

This report is focused on the nutritional value for turkeys of five wheat DDGS samples. All wheat DDGS samples were obtained from ENSUS Biorefinery, Wilton, UK. The sampling interval was between 14 and 21 days during a period of 90 days from January to April 2013, yielding 5 samples in total. All samples were stored in bags at ambient air temperatures in a dry store. The stored DDGS samples did not experience any freezing temperatures during this storage. A representative sample was taken from each of the five batches and the major chemical components were measured. Although the manufacturer followed the same procedures during the bioethanol, i.e. DDGS, production, different batches of wheat were used.

2.2. Husbandry and sample collection

All procedures were approved by The Animal Experimental Committee of Harper Adams University.

Nutrient availability were examined in a turkey poults experiment from 67 to 75 d age. Each of the five DDGS samples were incorporated into a nutritionally complete diet in meal form at 200 g/kg (800 g of the basal feed +200 g of each DDGS sample) (Table 1). The nutrient specification of the diets met the breeder's recommendation (Aviagen Ltd.). A sixth dietary treatment was also fed that was the basal feed only. Female Premium turkeys were obtained from a commercial hatchery (Faccenda Foods Ltd, Dalton, UK) at day old and were placed in a single floor pen and fed on a proprietary wheat-soybean turkey feed until 67 d of age. During the first two phases, from 0 to 28 and from 28 to 56 d age, diets contained 12.21 and 12.39 MJ/kg metabolisable energy, 285 and 270 g/kg crude protein, 18 and 16 g/kg available lysine, 13 and 12 g/kg methionine + cysteine, 15 and 13 g/kg Ca, 8 and 7 g/kg available P, respectively. From 56 days onwards, birds were fed the basal diet. Two birds were randomly allocated to one of 48 cages with 0.36 m^2 floor area and given the experimental diets. Each cage was equipped with a trough feeder and nipple drinker. Access to the feed and the water was *ad libitum*. There were 8 replicates for each diet. The experimental house was equipped with a negative pressure ventilation system to meet commercial recommendations. A standard temperature and lighting programs for turkeys were used (Aviagen, Turkeys ltd).

At 71 d of age, after 5 days given to adjust to the diets, the total droppings were collected for four days until the end of the study at 75 d age. Feed intake for the same period was recorded for the determination of dietary AMEn and total tract nutrient retention coefficients.

2.3. Chemical Analysis

Dry droppings samples were weighed and milled to pass through a 0.75-mm mesh. Gross energy concentrations of the control feed, DDGS and droppings were measured using an adiabatic bomb calorimeter (Model: 1261 Isoperibol Bomb Calorimeter, 100 Parr Instrument

Company, Moline, IL, USA). Nitrogen was determined using a Leco nitrogen analyser (Leco FP-528, Leco Corporation, St Joseph, MI, USA) according to AOAC method 968.06 (AOAC, 2000). Ether extract was determined according to AOAC methods 920.39 and 942.05, respectively (AOAC, 2000). The colour score of the stored DDGS samples was carried out using a Chroma Meter CR-400 from Konica Minolta (Sunderland, UK) to determine luminance and chromaticity scores using CIELAB scoring.

Non-starch polysaccharides (NSP) and total starch (TS) contents in the DDGS samples were determined following the methods of Englyst (1994) and Englyst (2000), respectively. The GE, DM, nitrogen and ether extract of each dried droppings sample and the experimental diets were determined as described for the feed samples. The AMEn of the diets was calculated following the method of Hill and Anderson (1958). The coefficients of total tract nutrient retention were determined as the difference between intake and voiding of the nutrient, divided by their respective intake.

2.4. Statistical procedure

The results of pure DDGS samples were statistically compared using a randomised block analysis of variance. Duncan's multiple range test was used to determine significant differences between diets. The observational unit was the cage with two birds. Statistical analyses were performed using the GenStat statistical software package (GenStat 17 release 3.22 for Windows; IACR, Rothamstead, Hertfordshire, UK). The AMEn and the nutrient retention coefficients of all diets, including the basal diet and diets including DDGS samples were determined. Then the AMEn and the nutrient retention coefficients of the pure DDGS samples were obtained by the substitution method (Finney 1978) using the data from the basal only.

Correlation coefficients were obtained for all chemical and physical characteristics of the wheat DDGS samples. In all instances, differences were reported as significant at $p \leq 0.05$.

3. Results

The chemical composition and the colour measurements of the wheat-DDGS used in the current study are presented in Table 2. The amount of oil was more variable than the protein content and the GE concentration, and ranged from 41.9 to 55.0 g/kg DM. The ash content was also variable, from 53.1 to 64.9 g/kg DM, and conversely related to the oil content of the DDGS samples. The DM content was uniform and ranged from 892 to 900 g/kg DM. The variation in the colour scores was relatively uniform although all readings were lower than 50. Variation in all proximate analysis and the colour scores of the present study were in agreement with Pedersen et al. (2014).

Xylose, glucose and arabinose were the main NSP constituent sugars in the wheat DDGS samples. The mean starch content of the DDGS batches was 33.0 g/kg DM, as batch C had the lowest starch content of 28.0 g/kg DM, and batch A had the highest starch content of 41.5 g/kg DM, respectively.

The AMEn of the DDGS from batch A was higher ($p = 0.048$) compared to those from batches B and C, but did not differ ($p > 0.05$) from the rest of DDGS samples. There were no differences ($p > 0.05$) in DMR, NR and FD between the DDGS samples from different batches used in this study.

The AMEn of the DDGS samples was positively correlated ($p < 0.05$) to starch ($r = 0.895$), the red light spectrum (a) ($r = 0.916$) and the NSPn ($r = 0.940$), respectively (data not presented in tables).

4. Discussion

The analysed dietary protein and ether extract contents differed from the calculated values for the basal diet, which could probably be due to the differences between the composition of the actual ingredients that were used in the present study and the values given by the data set in the spreadsheets used for dietary calculation.

The objective of the current experiment was to determine the AMEn contents and nutrient retention coefficients of five different wheat-DDGS batches for turkeys. A single production plant produced the DDGS batches over a relatively short period. The variation in chemical composition between batches (for example ranges of 8.5 g/kg CP, 13.1 g/kg in oil, 20.4 g/kg in total NSP, and 13.5 g/kg in starch) were either due to small differences in processing conditions or differences in wheat grain used in the production process. The results confirm the importance of research on batch variability of wheat DDGS to better understand the source of variation that influence its feeding quality for turkeys.

The approximate nutrient, polysaccharide and GE contents of the experimental wheat DDGS samples were in a range similar to published reports (Bolarinwa and Adeola 2012; Adebiyi and Olukosi 2015). As expected (Świątkiewicz and Koreleski 2008), the studied wheat DDGS contained between two and three times more NSP, ether extract, protein and ash and about 20 times less starch compared to average wheat starch contents, in line with fermentation process during DDGS production.

The AMEn of the studied wheat-DDGS samples was relatively high, 13.42 MJ kg/DM, compared to the values reported by Cozannet et al. (2010), 9.60 MJ kg/DM, but slightly lower than those reported by Adebiyi and Olukosi (2015), 14.04 MJ kg/DM, respectively. When applying the substitution method on the data reported by Opoku et al. (2015c) a value of 14.66 MJ kg/DM was obtained for the wheat DDGS sample used. Much higher AMEn values would be obtained if the substitution method is applied to another report by Opoku et al. (2015b).

However, it can be speculated that the difference in AMEn values in wheat-DDGS between the current study and other reports is due to differences in experimental conditions, techniques used, birds age, dietary composition, and also chemical composition of DDGS and bioethanol plant where the samples were produced. For example, Adebiyi and Olukosi (2015) used 20 d old BUT10 male turkeys, Cozannet et al. (2010) used 70 d old male BUT9 turkeys, Opoku et al. (2015c) used 21 d old Hybrid Converter female turkeys, and 70 d old female BUT Premium turkeys were used in the present report. In addition, Adebiyi and Olukosi (2015) had DDGS inclusion at 0, 300 and 600 g/kg diet, and used titanium dioxide as indigestible marker to enable determination of AMEn content by the index method. Opoku et al. (2015c) included DDGS at 0, 100, 200 and 300 g/kg diet, and used acid insoluble ash as indigestible marker. Cozannet et al. (2010) included DDGS at 0 and 250 g/kg and used total collection technique for AMEn determination. In the present report, DDGS was included at 0 and 200 g/kg and total collection technique was used. Dietary composition between studies also differ. In addition, storage of wheat DDGS may be a reason for differences in metablisable energy (Whiting et al. 2016).

The differences in aforementioned metabolisable energy values of wheat- DDGS suggest that more uniform methodology for determining energy value of wheat-DDGS for turkeys is needed. Although variation in chemical and physical characteristics of wheat-DDGS samples is one of the reasons for differences in available energy, employed methodology, dietary composition, age, and hybrids used should be given also consideration.

It is now well documented that bioethanol plants have significant impact on nutritive value of wheat and maize DDGS (Bandegan et al. 2009; Cozannet et al. 2010; Nuez Ortin and Yu 2009). Batch variation in composition of maize DDGS produced by a single production plant has been observed (Belyea et al. 2004; Bottger and Sudekum 2017). Batch-to-batch variations in AMEn in wheat DDGS from the same bioethanol processing plant have been also reported in broiler and layer studies (Whiting et al. 2016, 2017). The chemical composition of wheat, e.g., NSP and resistant starch varies, thus the polysaccharide content of DDGS produced will also be variable. The main factors affecting the variability of wheat include, crop nutrition, location, seasonal factors, and genetics (Pirgozliev et al. 2003). Since wheat is the raw material for DDGS production, the observed variability is not a surprise.

Dietary metabolisable energy is widely used to describe the available energy concentration in poultry feedstuffs. The availability of dietary energy depends on the availability of starch, protein and fat, all of which may be impaired by anti-nutritive factors. However, the starch content in the wheat-DDGS samples in this study was reduced approximately 20 times compared to average wheat starch content; thus, the overall metabolisable energy contribution of starch is not significant. In addition, because of processing, some of the residual starch will be in the form of resistant starch and will therefore, essentially act as a NSP (Sharma et al., 2010).

In agreement with Cozannet et al. (2010), the colour score, in particular the red index was highly correlated to the AMEn in the DDGS samples. All samples were dark ($L < 50$) in connection with probable overheating during the DDGS drying process and a possible Maillard reaction. The Maillard reaction is regarded as being primarily responsible for causing chemical heat damage to protein within DDGS (Cromwell et al. 1993; Waldroup et al. 2007). A number of publications have associated damaged protein with darker samples of DDGS and conversely better quality protein in lighter samples (Cromwell et al. 1993; Fastinger and Mahan 2006). Sharma et al. (2010) reported that differences in temperature during the liquefaction stage may be a reason for differences in resistant starch content, thus suggesting that a variation in the temperature during the process in the same plant may exist. In addition, Classen et al. (2014) found that all stages of heat application during wheat DDGS production negatively affected the content and digestibility of amino acids. Lysine is particularly susceptible to heat damage initiated during this process (Smith et al. 2006). Diets containing wheat DDGS may need more lysine supplementation to meet the requirements of the birds (Cozannet et al. 2010; Bolarinwa and Adeola 2012).

DeGroote (1974) reported that the efficiency of energy utilization from dietary protein, carbohydrates, and fats is 0.6, 0.7, and 0.9, respectively. In addition, fats contains higher amount of energy compared to carbohydrates and protein, thus variation in ether extract content can explain variation in available energy content of DDGS.

5. Conclusions

The results showed that the feeding value of different wheat DDGS batches produced by a single production plant might vary when fed to turkeys. The relatively low colour scores of the samples indicates the need to consider the level and control of heat application in wheat ethanol production. When formulating poultry diets containing DDGS, information on energy and nutrient contents and availability is important to ensure diets are balanced. In general, findings from this study indicate bioavailability of energy and most nutrients to in the range of published data with turkeys, and to vary between batches.

Acknowledgements

We thank Richard James and Rose Crocker for their technical support.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Adebiyi AO, Olukosi OA. 2015. Metabolizable energy content of wheat distillers' dried grains with solubles supplemented with or without a mixture of carbohydrases and protease for broilers and turkeys. Poult Sci. 94:1270–1276.

Adedokun SA, Adeola O, Parsons CM, Lilburn MS, Applegate TJ. 2008. Standardized ileal amino acid digestibility of plant feedstuffs in broiler chickens and turkey poults using a nitrogen-free or casein diet. Poult Sci. 87:2535–2548.

[AOAC] Association of Official Analytical Chemists. 2000. Official methods of analysis of AOAC. 17th ed. Vol. II. Gaithersburg (MD): Association of Official Analytical Chemists.

Böttger C, Südekum K-H. 2017. Within plant variation of distillers dried grains with solubles (DDGS) produced from multiple raw materials in varying proportions: Chemical composition and in vitro evaluation of feeding value for ruminants. Anim Feed Sci Technol. 229:79–90.

Cozannet P, Lessire M, Gady C, Metayer JP, Primot Y, Skiba F, Noblet J. 2010. Energy value of wheat dried distillers grains with solubles in roosters, broilers, layers, and turkeys. Poult Sci. 89:2230–2241.

Bandegan A, Guenter W, Hoehler D, Crow GH, Nyachoti CM. 2009. Standardized ileal amino acid digestibility in wheat distillers dried grains with solubles for broilers. Poult Sci. 88:2592–2599.

Belyea RL, Rausch KD, Tumbleson ME. 2004. Composition of corn and distillers dried grains with solubles from dry grind ethanol processing. Biores Technol. 94:293–298.

Bolarinwa OA, Adeola O. 2012. Energy value of wheat, barley and wheat distillers dried grains with solubles for broilers chickens using the regression method. Poult Sci. 91:1928–1935.

Classen HL, Abbott D, Nickerson M. 2014. Effect of hightemperature ethanol fuel processing on the digestibility of wheat protein derived from various stages of ethanol production in broiler chickens. Poult Sci. 93(Suppl.1):51.

Cromwell GL, Herkelman KL, Stahly TS. 1993. Physical, chemical, and nutritional characteristics of distillers dried grains with solubles for chicks and pigs. J Anim Sci. 71:679-686.

De Groote G. 1974. A comparison of a new net energy system with the metabolisable energy system in broiler diet formulation, performance and profitability. Br Poult Sci. 15:75–95.

Fastinger ND, Mahan DC. 2006. Determination of the ileal amino acid and energy digestibilities of corn distillers dried grains with solubles using grower-finisher pigs. J Anim Sci. 84:1722 -1728.

Kluth H, Rodehutscord M. 2006. Comparison of amino acid digestibility in broiler chickens, turkeys, and pekin ducks. Poul Sci. 85:1953–1960.

Nuez Ortin W., Yu P. 2009. Nutrient variability of wheat DDGS, corn DDGS and blend DDGS from bioethanol plants. J Sci Food Agric. 89:1754-1761.

Finney DJ. 1978. Statistical Method in Biological Assay. 3rd ed. Buckinghamshire. Charles Griffin & Company Limited.

Opoku EY, Classen HL, Scott TA. 2015a. Evaluation of inclusion level of wheat distillers dried grains with solubles with and without protease or β-mannanase on performance and water intake of turkey hens. Poult Sci. 94:1600–1610.

Opoku EY, Classen HL, Scott TA. 2015b. The effects of extrusion of wheat distillers dried grains with solubles with or without an enzyme cocktail on performance of turkey hen poults. Poult Sci. 94:185–194.

Opoku EY, Classen HL, Scott TA. 2015c. Effects of wheat distillers dried grains with solubles with or without protease and β-mannanase on the performance of turkey hen poults. Poult Sci. 94:207–214.

Pirgozliev V, Birch CL, Rose SP, Kettlewell PS, Bedford MR. 2003. Chemical composition and the nutritive quality of different wheat cultivars for broiler chickens. Br Poult Sci. 44:464–475.

Sharma V, Rausch KD, Graeber JV, Schmidt SJ, Buriak P, Tumbleson ME, SinghV. 2010. Effect of resistant starch on hydrolysis and fermentation of corn starch for ethanol. Appl Biochem Biotechnol. 160:800–811.

Smith TC, Kindred DR, Brosnan JM, Weightman RM, Shepherd M, Sylvester-Bradley R. 2006. Wheat as a Feedstock for Alcohol Production. UK: HGCA.

Świątkiewicz S, Koreleski J. 2008. The use of distillers dried grains with solubles (DDGS) in poultry nutrition. W Poult Sci J. 64:257-264.

Waldroup PW, Wana Z, Coto C, Cerrate S, Yan F. 2007. Development of standardized nutrient matrix for corn distillers dried grains with solubles. Int J Poult Sci. 6:478-483.

Westreicher-Kristen E, Steingass H, Rodehutscord M. 2012. Variations in chemical composition and in vitro and in situ ruminal degradation characteristics of dried distillers' grains with solubles from European ethanol plants. Arch Anim Nutr. 66:458–472.

Whiting IM, Pirgozliev V, Rose SP, Wilson J, Amerah AM, Ivanova SG, Staykova GP, Oluwatosin OO, Oso AO. 2016. Nutrient availability of different batches of wheat distillers dried grains with solubles with and without exogenous enzymes for broiler chickens. Poult Sci. 96:574-580.

Whiting I, Pirgozliev V, Rose SP, Karadas F, Mirza MW, Sharpe A. 2017. The temperature of storage of a batch of wheat distillers dried grains with solubles samples on their nutritive value for broilers, Brit Poult Sci – in press (https://doi.org/10.1080/00071668.2017.1380297)

Table 1. Experimental basal diet[*]

Ingredients [%]	
Wheat	53.5
Prairie meal	2.5
Wheatfeed	5.0
Soybean meal	30.0
L-Lysine HCl	0.4
DL-methionine	0.3
L-threonine	0.1
Soya oil	4.0
Limestone	1.0
Dicalcium phosphate	2.5
Salt	0.3
Turkey premix[†]	0.4
Calculated provisions	
AME [MJ/kg]	12.6
CP [g/kg]	235
Ether extract [g/kg]	56
Av Lysine [g/kg]	13.8
Meth + Cysteine [g/kg]	9.9
Ca [g/kg]	12.1
Av P [g/kg]	6.1
Analysed values	
DM [g/kg]	879
GE [MJ/kg]	17.3
CP [g/kg]	233
Ether extract [g/kg]	54

[*]DDGS containing diets were fed as a part of complete diet comprised 200 g/kg of each experimental wheat DDGS sample and 800 g/kg of the basal.

[†]Provided per kg feed: retinol, 2160 μg; cholecalciferol, 75 μg; α-tocopherol, 25 mg; menadione, 1.5 mg; riboflavin, 5 mg; pantotenic acid, 8 mg; cyanocobalamin, 0.01 mg; pyridoxine, 1.5 mg; thiamine, 1.5 mg; folic acid, 0.5 mg; niacin, 30 mg; biotin, 0.06 mg; iodine, 0.8 mg; copper, 10 mg; iron, 80 mg; selenium, 0.3 mg; manganese, 80 mg; and zinc, 80 mg.

Table 2. Proximate composition and colour measurements of the experimental wheat DDGS samples [g/kg DM*]

DDGS	DM [g/kg]	Ash [g/kg]	Ether extract [g/kg]	Crude protein [g/kg]	Gross energy [MJ/kg]	Colour measurements†		
						L	a	b
A	896	54.9	49.8	318.5	21.78	38.6	10.2	19.7
B	898	64.9	42.8	326.2	20.29	37.7	9.3	18.0
C	900	58.2	41.9	327.0	21.42	36.4	9.3	17.1
D	892	55.1	51.3	322.4	21.77	35.6	9.8	17.7
E	895	53.1	55	325.3	21.68	36.8	9.5	18.1
SD‡	3.03	4.66	5.64	3.87	0.63	1.16	0.38	0.97

*DM: dry matter; †Colour measurements as follows: L [luminance]; a [red index]; b [yellow index]; ‡SD: standard deviation.

Table 3. Polysaccharide composition of the experimental wheat DDGS samples [g/kg dry matter]

Batch	Fraction	Arabinose	Xylose	Mannose	Galactose	Glucose	Galacturonic acid	NSP[†]	Starch
A	NSPs[‡]	11.2	15.6	5.6	2.2	6.7	4.5	45.8	
	NSPn[#]	43.5	67.0	6.7	8.9	63.6	0.0	189.7	
	NSPt[§]	54.7	82.6	12.3	11.2	70.3	4.5	235.5	41.5
B	NSPs	13.4	24.5	6.7	5.6	14.5	5.6	70.2	
	NSPn	40.1	56.8	6.7	5.6	57.9	0.0	167.0	
	NSPt	53.5	81.3	13.4	11.1	72.4	5.6	237.2	28.5
C	NSPs	13.3	23.3	4.4	4.4	10.0	5.6	61.1	
	NSPn	38.9	61.1	6.7	6.7	62.2	0.0	175.6	
	NSPt	52.2	84.4	10.0	11.1	72.2	5.6	235.6	28.0
D	NSPs	13.5	19.1	4.5	4.5	7.8	3.4	52.7	
	NSPn	41.5	62.8	7.8	6.7	61.7	0.0	180.5	
	NSPt	54.9	81.8	11.2	11.2	70.6	3.4	233.2	31.9
E	NSPs	11.2	14.5	4.5	3.4	5.6	0.0	39.1	
	NSPn	40.2	63.7	6.7	7.8	60.3	0.0	178.8	
	NSPt	51.4	78.2	10.1	11.2	65.9	0.0	216.8	35.0
SD[⁑]	NSPs	1.21	4.47	1.00	1.28	3.52	2.32	12.28	
SD	NSPn	1.75	3.74	0.49	1.25	2.16	0.00	8.22	
SD	NSPt	1.53	2.26	1.46	0.05	2.62	2.32	8.43	5.54

[†]NSP: non-starch polysaccharides; [‡]s: soluble; [#]n: non-soluble; [§]t: total; [⁑]SD: standard deviation.

Table 4. Metabolisable energy and nutrient availability of the experimental wheat DDGS samples determined from 71 to 75 days of age.[*,≠]

DDGS	AMEn[‡] [MJ/kg DM[#]]	DMR[§] [g/kg]	NR[†] [g/kg]	FD[⁑] [g/kg]
A	13.64[b]	0.666	0.695	0.851
B	13.19[a]	0.642	0.678	0.874
C	13.26[a]	0.649	0.682	0.884
D	13.52[ab]	0.640	0.676	0.876
E	13.48[ab]	0.671	0.707	0.889
CV%[¥]	2.4	5.5	5.3	5.5
SEM[⁋]	0.112	0.0126	0.0129	0.0143
P	0.048	0.317	0.396	0.415

[*]Each mean represents values from eight replicate pens of two turkeys each; [‡]AMEn: apparent metabolisable energy, N-corrected; [#]DM: dry matter; [§]DMR: dry matter retention; [†]NR: nitrogen retention; [⁑]FD: fat digestibility; [¥]CV%: coefficient of variation; [⁋]SEM: standard error of the mean.

[a,b] Within AMEn values in a column not sharing a common superscript are significantly different.

[≠]The determined values for AMEn, DMR, NR and FD of the basal diet were 13.90 MJ/kg DM, 0.663, 0.706 and 0.900, respectively.