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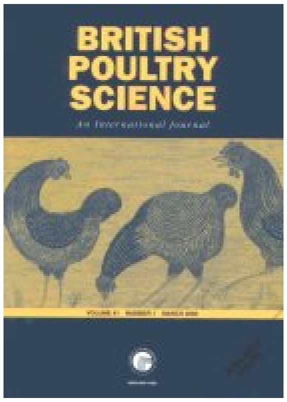

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Nutrient content and digestibility of different batches of wheat distillers dried grains with solubles for laying hens

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ABSTRACT

1. Four batches of wheat distillers dried grains with solubles (DDGS) produced by a single production plant were used to investigate variation in digestible energy (DE) and nutrient digestibility for laying hens.

2. A total of 144 Hy-Line Brown laying hens were allocated to eight treatment groups in replicates of six. Experimental diets were prepared by replacing the basal feed with either 150 g/kg or 300 g/kg of each batch of DDGS.

3. Chemical analysis of the DDGS showed variation between the different batches. Largest coefficients of variation were observed for starch (0.546) and total soluble non-starch polysaccharides (NSP; 0.276).

4. Digestible energy and the nutrient digestibility of each diet was measured using the ileal collection technique. Data were statistically analysed as a blocked 2 x 4 factorial design analysis of variance (ANOVA).

5. Variability between the different diets were observed for digestible energy and the digestibility of certain nutrients ($P<0.05$).

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6. The observed differences in energy utilisation and nutrient digestibility in laying hens suggested that the feeding quality of diets containing different wheat DDGS batches produced by a single production plant may still have large variation.

Key words: Wheat DGGS, amino acids, nutrient digestibility, digestible energy, laying hens

INTRODUCTION

In the UK, wheat is the primary cereal crop used to produce ethanol. The main by-product from this industry is wheat distillers dried grains with solubles (DDGS; Smith *et al*. 2006). The conversion of starch to ethanol during processing results in DDGS containing up to three times the concentration of some nutrients compared with the original grain (Świątkiewicz and Koreleski, 2008). The use of DDGS in feeds for monogastrics, particularly poultry, is limited due to its relatively high level of fibre (Nyachoti *et al*. 2005; Thacker and Widyaratne, 2007), as poultry lack the digestive enzymes required to breakdown fibrous feed components (Bedford and Schulze, 1998). Other issues related to the feeding quality of DDGS are mainly associated with processing parameters. Nutrient availability of DDGS has been shown to vary considerably between batches produced by different production sites (Belyea *et al*. 2004; Liu, 2011; Whiting *et al*. 2016; Pirgozliev *et al*. 2018). It has been suggested that some of the variability is caused by differences in the blended proportions of wet distillers' grains (WDG) and condensed distillers with solubles (CDS) (Belyea *et al*. 2010; Han and Liu, 2010). Maillard reactions may occur as a result of high temperatures used during cooking and drying, with lysine being particularly susceptible to heat damage (Smith *et al*. 2006). Residual starch may pose a problem, as not all of the starch is converted into its constituent sugars during ethanol

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production, and this unconverted starch will likely be in the form of indigestible resistant starch (RS) (Sharma *et al*. 2010).

It has been reported recently that a storage of DDGS may affect its feeding value for broilers (Whiting *et al*. 2017). In addition to processing differences, the chemical composition of cereal grains is variable (Pirgozliev *et al*. 2003; Azhar *et al*. 2019), thus the nutritive value of DDGS produced will be inconsistent.

The aim of the present experiment was to investigate the effect of feeding four different batches of wheat DDGS produced by a single production site (Ensus Limited, UK) to laying hens when incorporated at two inclusion levels.

MATERIALS AND METHODS

Wheat DDGS

Four batches of wheat DDGS used in the study were produced by a single manufacturer (ENSUS Bio refinery, Wilton, UK). Batches 1, 2 and 3 were manufactured in late 2012, early 2013 and were obtained from S.C. Feeds Ltd, Staffordshire. The fourth batch was manufactured in January 2012 and was obtained from Target Feeds Ltd, Shropshire. All batches were stored in bags at ambient air temperatures in a dry store until the study commenced in February 2013. A representative sample was taken from each of the four batches and the major chemical components were measured. Analyses were carried out in duplicate and are reported on a dry matter basis.

Proximate analysis

Analyses were carried out separately on the basal feed and DDGS prior to mixing. To determine the correct chemical composition of each experimental treatment, individual diets were recalculated from the analysis of the basal feed and DDGS. Dry matter (DM) of the basal feed and DDGS was determined by drying samples in a forced air oven for 48 hours at 100°C (AOAC Official Method 934.01, 2006). Ash of the basal feed and DDGS was measured in a muffle furnace at 500°C for 24 hours (AOAC Official Method 942.05, 2005). Crude protein

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(CP) calculated as N x 6.25 of the basal feed, DDGS and digesta was determined by the combustion method (AOAC Official Method 990.03, 2006) using Leco (FP-528 N; Leco Corp., St. Joseph, MI) with EDTA as a standard (Sweeney, 1989). Oil (as ether extract) in the basal feed, DDGS and digesta was extracted with petroleum ether using a Soxtec Avanti 2050, Foss UK Ltd (AOAC Official Method 945.16, 2005). Gross energy (GE) of the basal feed, DDGS and digesta was measured using an adiabatic bomb calorimeter (Parr 6200 Instrument Company, Moline, IL, 61265, USA; FAO, 2003). Neutral detergent fibre (NDF) in the basal feed and DDGS was analysed according to Van Soest *et al*. (1991), using an FT 122 Fibertec™ hot extraction unit (200-230V). Titanium dioxide (TiO_2) in diets and digesta was determined using the method developed by Short *et al*. (1996). Total starch in the DDGS was determined by a modified version of Englyst *et al*. (2000) and non-starch polysaccharides (NSP) in the DDGS was determined by the method of Englyst *et al*. (1994). Amino acids (AA) in the basal feed, DDGS and digesta were determined by SSNIFF Spezialdiäten GmbH (Soest, Germany) according to the EC directives 2000/45/EC for tryptophan (OJEC, 2000), and EC/98/64 (L 257/16) for the rest of the amino acids (OJEC, 1998). Colour scores of each DDGS sample were measured using an L*a*b* colour space (Konica Minolta, Chroma Meter CR-400). L* indicated lightness, while a* and b* were the chromaticity coordinates. The bulk density of each of the DDGS samples was measured using a chondrometer, a vessel with a known volume, providing constant conditions (Farm-Tec, Scunthorpe, UK).

Diet formulation

Eight diets in total were used in this experiment. A wheat-soybean meal basal diet containing 11.89 MJ/kg AME and 172.5 g/kg crude protein was prepared (Table 1). Four diets containing 850 g/kg of the basal feed were mixed with 150 g/kg of each of the four DDGS batches. Similarly, the remaining four diets contained 700 g/kg of the basal feed and 300 g/kg of the respective DDGS batches. The diets did not contain any coccidiostat, antimicrobial growth promoters, prophylactic or other similar additives. All diets were fed as mash with 5 g/kg TiO_2 added on top as an indigestible marker. The birds were fed a single proprietary layers feed, until 22 weeks of age, when approximately 90% egg production was reached. The diets were administered for eight days with six replicate cages of birds per treatment.

Table 1 here

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Birds and housing

The study was approved by the Animal Experimental Committee of Harper Adams University. A total of 144, sixteen-week old Hy-Line Brown laying hens were obtained from a commercial supplier (Country Fresh Pullets Ltd, Oswestry, Shropshire). The birds were randomly allocated to 48 layer cages (over three tiers) in groups of three. Each cage was equipped with a separate feeder at the front and two nipple drinkers inside. Cage dimensions were 45 cm x 40 cm x 50 cm and consisted of a wire mesh flooring which contained no bedding material. Temperature was maintained at 21°C and relative humidity was between 50 and 70%. The birds had *ad libitum* access to feed and water. Lighting was set to give 10 hours day length upon arrival and, at 20 weeks of age, lighting was increased by 30 minutes each week and 12 hours light was given each 24 hours between 23 and 24 weeks of age. On the final day of the study the birds were killed by cervical dislocation and digesta were collected from the distal ileum and pooled into one pot per cage. Digesta were immediately frozen at -20°C for 24 hours and then freeze dried. An indigestible marker technique was used to determine digestible energy (DE) and nutrient digestibility from the ileal digesta.

Statistical analysis

The experiment was conducted using a randomised block design. To determine digestibility coefficients, data for this study was analysed as a blocked 2 x 4 factorial design analysis of variance (ANOVA) using Genstat 17th edition (Lawes Agricultural Trust, VSN International Ltd, Oxford, UK). The main effects analysed were related to the effects of the different DDGS batches and the two inclusion rates. In all instances, differences were reported as significant at 95% confidence limits ($P<0.05$). Duncan's multiple range test was used to determine significant differences between the four DDGS samples.

RESULTS

Chemical characteristics of the studied DDGS

Proximate analysis

The chemical compositions of the wheat DDGS samples were variable for each criterion (Table 2). The DM content ranged from 843 to 900 g/kg with batch 4 containing ~6% less DM than the mean of the other DDGS samples. Gross energy ranged from 21.16 (batch 4) to 21.78 MJ/kg DM (batch 1) . Batch 4 contained ~10% less protein than the mean of the other DDGS samples. Oil concentration ranged from 41.9 (batch 2) to 61.2 g/kg DM (batch 4). The content of NDF ranged from 442.2 (batch 4) to 493.3 g/kg DM (batch 1). Ash content ranged from 53.1 (batch 3) to 58.2 g/kg (batch 2). Bulk density ranged from 37.0 (batch 1) to 54.9 kg/hl (batch 4), while lightness from the colour scores ranged from 36.4 (batch 2) to 43.8 (batch 4). The greatest coefficients of variation (CV) were observed for oil (0.157) and bulk density (0.176).

Table 2 here

Amino acid composition

The AA composition of the studied DDGS batches are presented in Table 3. Among the indispensable AA (IAA), mean methionine (5.3 g/kg DM) and lysine (7.0 g/kg DM) were low relative to other AA. In contrast, IAA with the highest mean content were leucine (27.3 g/kg DM) and phenylalanine (16.8 g/kg DM). The greatest CV among the IAA was seen for tryptophan (0.099), while the greatest CV among the dispensable AA (DAA) was observed for glutamic acid (0.080).

Table 3 here

Polysaccharide composition

The polysaccharide composition of the studied DDGS batches are presented in Table 4. The distribution of constituent sugars for the studied DDGS are in order of xylose, glucose, arabinose, mannose, galactose and galaturonic acid for batches 1 and 4 and in order of xylose, glucose, arabinose, galactose, mannose and galaturonic acid for batches 2 and 3. Total NSP content of the four batches ranged from 217.5 (batch 3) to 253.7 g/kg DM (batch 4). Total soluble and insoluble NSP content ranged from 32.7 (batch 4) to 59.9 g/kg DM (batch 2) and

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174.8 (batch 2) to 221.0 g/kg DM (batch 4), respectively. Starch content ranged from 28.0 (batch 2) to 88.1 g/kg DM (batch 4). The greatest CV's for soluble, insoluble and total NSP was observed for galaturonic acid, while a large CV of 0.565 was observed for starch content.

Table 4 here

Digestibility of energy and nutrients

Digestibility coefficients for energy, protein, DM and fat are shown in Table 5. Differences were observed between the four batches of DDGS, with batch 1 having the lowest DE (P=0.048), DM (P=0.012) and fat digestibility (P<0.001). No differences were observed between the different batches for protein digestibility (PD). Increasing DDGS inclusion rate from 15 to 30% improved (P<0.001) DM and fat digestibility. No interactions (P>0.05) were observed between the DDGS batches and inclusion level.

Table 5 here

Digestibility coefficients for both IAA and DAA are shown in Tables 6 and 7, respectively. Batch 2 had the highest histidine digestibility (P=0.038). Differences between DDGS samples were evident for cysteine, glutamic acid, glycine, proline and serine (P<0.05).

Tables 6 and 7 here

DISCUSSION

The purpose of the experiment reported in this paper was to examine the variability between batches of wheat DDGS produced by the same manufacturer on digestible energy and nutrient digestibility in diets for laying hens. Different manufacturing processes at different production plants and seasonal wheat differences may further increase the variability of DDGS samples

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that will be available to poultry feed manufacturers. However, the present comparison remains valuable to inform the poultry industry of the variability they can expect within each harvest year.

Chemical composition of the wheat DDGS batches

Results from the chemical analysis were generally in agreement with data published by others (Thacker and Widyaratne, 2007; Vilariño *et al.* 2007; Bandegan *et al.* 2009; Oryschak *et al.* 2010; Hazzledine *et al.* 2011; Pedersen *et al.* 2014). Despite batch 4 having the lowest protein content, it scored the highest value for lightness (43.8) compared with the other batches of DDGS. Cozannet *et al.* (2010b) recommended colour scoring DDGS as a rapid and reliable method for estimating AA digestibility. Although it must be advised that DDGS with L* scores lower than 50 may have been exposed to Maillard reactions, thus resulting in DDGS with reduced protein quality. It should be noted that each of the studied batches of wheat DDGS had lightness values lower than 50. The AA composition of the studied wheat DDGS were comparable to values reported by Kluth and Rodehutscord (2010). Among the IAA the greatest CV was for observed tryptophan (0.099), while the greatest CV among the DAA was observed for proline (0.090). Lowest contents of IAA were observed for lysine (7.0 g/kg DM) and methionine (5.3 g/kg DM), although average values were similar to those reported by the NRC (2012).

Total NSP content of the studied DDGS was similar to that reported by Widyaratne and Zijlstra (2007) and Pederesen *et al.* (2014). Compared with the total NSP content of the different batches of the studied DDGS, the content of certain constituent sugars and the total soluble and insoluble fractions varied considerably. With the exception of galacturonic acid, the CV values of the studied wheat DDGS were greatest for the sNSP fraction. In addition, the large range observed among the different batches for starch (28.0 to 88.1 g/kg DM) are similar to findings reported by Cozannet *et al.* (2010a). Residual starch is directly related to the fermentation process and is particularly dependent on fermentation time, yeast and the use of enzymes. The large variation in starch content among the different batches of DDGS may have an impact on ethanol yield and may be of useful for the bioethanol industry to take this into account.

Digestibility of energy and nutrients

When formulating poultry diets containing DDGS, information on energy and nutrient availability is important to ensure diets are balanced. When considering production costs for poultry feeds, determining accurate measures of available energy is crucial. The most common measure of energy contained in feedstuffs for poultry is AME (Abdulla *et al*. 2016). Although AME takes into account energy loss in urine, it may be confounded by loss of energy in fermentation in the caeca that has little benefit to the bird. However, it may be speculated that the relatively high insoluble NSP contents, and numerically low CP digestibility seen in samples 1 and 4, indicated that, if determined, dietary N corrected AME may follow similar variation as DE. In addition, research conducted by Pirgozliev *et al*. (2003), suggested that ME does not always relate to the feeding value of diets. Little data are available on the digestible energy of wheat DDGS for poultry, particularly for laying hens, and any differences may be important in evaluating different batches of DDGS that have high dietary fibre contents. Ileal digesta have already been used to determine AA and CP digestibility, thus, measuring DE was fairly simple. High NSP content in cereals are associated with low available energy in poultry feeds (Annison, 1991; Choct *et al*. 1999). A number of factors have been found to affect the bioavailability of nutrients in DDGS. These include the type of DDGS, quality of the original grain and production processes.

It has been previously reported that the presence of soluble pentosans considerably reduced the digestibility of fat (Dänicke *et al*. 1999). However, in the present study, there was no relationship between fat digestibility and soluble NSP content for the four DDGS batches. Findings from a broiler study by Romero *et al*. (2014) suggested that fat digestibility was less affected by wheat arabinoxylans in older birds, such as those used in the present study. In addition, the improved dietary fat and dry matter digestibility observed when increasing DDGS inclusion rate from 15 to 30% may have been due to the increased fat content in the diets, which might improve overall nutrient availability and, thus, dry matter digestibility.

The results of the present study have shown that there is a large and important variation in the digestible energy content between different batches of wheat DDGS, which may correlate to insoluble NSP contents. These differences will affect the economic value of the DDGS for use in practical laying hen feeds.

Protein and amino acid digestibility

Accurate information on the digestible protein and amino acid content of wheat DDGS is crucial and enables the poultry feed industry to formulate biologically and economically efficient diets. Precise data on digestible amino acid levels in feed ingredients for poultry allows the feed industry to optimise the efficiency of diet preparation and minimises

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overfeeding of amino acids, thereby optimising bird performance and feed cost (Pirgozliev *et al*. 2010; Tahir and Pesti, 2012). Digestibility coefficients for lysine are low, although this was expected because of the high temperatures used during the manufacturing process and agreed with studies using maize DDGS (Fontaine *et al*. 2007).

CONCLUSIONS

Wheat DDGS is now reliably available for compounders to use in animal feeds. The economic value of any feedstuff depends on its price and the content of available nutrients for a particular strain and age of livestock. The present study provided information on digestible energy and nutrient digestibility of four different wheat DDGS batches when incorporated into diets for adult laying hens at two inclusion rates. Stochastic feed formulation techniques may now be employed by poultry nutritionists to account for variability in the available nutrient content between different batches of the same feedstuff. Stochastic feed formulation methods need to include data on batch variability for each of the nutrients that they consider. Differences between production sites will probably further increase the variability of the overall number of batches that are available to the industry. However, the variability estimates are valid for practical feed compounders that will primarily buy their DDGS batches from one production factory only.

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Table 1. Chemical composition and ingredients of the basal diet

Ingredient	Amount g/kg
Wheat	687.0
Hipro Soya bean meal	130.0
Full fat soya	70.0
Soya oil	10.0
Lysine	1.0
Methionine	2.0
Threonine	1.0
Limestone	85.0
Dicalcium phosphate	10.0
Salt	3.0
Vitamin and trace element premix[1]	1.0
Calculated composition (as fed basis)	
ME (MJ/kg)	11.89
CP	172.5
Ca	34.0
Available P	3.1
Na	1.7
Analysed values (DM basis)	
DM	876.9
GE (MJ/kg)	13.08
CP	138.6
Fat	34.8
NDF	70.1

[1] Vitamin and mineral premix provided (units 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.

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281 *Table 2. Proximate analysis, bulk density and colour measurements of the studied wheat DDGS samples*

	Batch 1	Batch 2	Batch 3	Batch 4	CV
Dry matter (g/kg)	896.0	900.0	895.0	843.0	0.031
Gross energy (MJ/kg DM)	21.78	21.42	21.68	21.16	0.013
Protein (g/kg DM)	353.9	363.0	363.3	324.8	0.052
Oil (g/kg DM)	49.8	41.9	55.0	61.2	0.157
Neutral detergent fibre (g/kg DM)	493.3	490.8	486.7	442.2	0.051
Ash (g/kg)	54.9	58.2	53.1	57.5	0.042
Bulk density (kg/hl)	37.0	40.7	42.9	54.9	0.176
Colour measurements					
L*	38.6	36.4	36.8	43.8	0.088
a*	10.2	9.3	9.5	9.5	0.041
b*	19.7	17.1	18.1	21.8	0.107

282 CV = coefficient of variation

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Table 3. Amino acid composition of the studied DDGS sample (g/kg DM)

	Batch 1	Batch 2	Batch 3	Batch 4	CV
Ala	16.1	14.7	17.1	16.9	0.067
Arg	13.9	13.2	13.6	13.2	0.025
Asp	18.7	17.9	19.1	18.7	0.027
Cys	6.0	5.9	6.2	5.9	0.024
Glu	91.6	93.1	93.3	78.5	0.080
Gly	14.3	14.2	14.7	13.4	0.038
His	6.9	6.8	7.3	7.0	0.031
Ile	13.4	13.3	14	12.9	0.034
Leu	27.0	25.0	29.1	28.0	0.064
Lys	6.9	6.8	7.1	7.0	0.019
Met	5.3	4.9	5.5	5.3	0.048
Phe	17.2	16.6	17.7	15.8	0.049
Pro	28.9	33.2	35.4	30.5	0.090
Ser	12.0	11.7	12.2	11.4	0.030
Thr	9.9	9.5	10.1	9.5	0.031
Try	3.7	4.2	3.3	3.7	0.099
Tyr	9.1	8.2	8.9	8.8	0.044
Val	17.1	16.6	17.8	16.4	0.037

CV = coefficient of variation

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288 *Table 4. Polysaccharide composition of the studied wheat DDGS samples (g/kg DM)*

	Batch 1	Batch 2	Batch 3	Batch 4	CV
sNSP					
Xylose	15.2	23.0	14.3	9.0	0.375
Arabinose	11.1	12.9	11.5	11.2	0.071
Mannose	5.7	4.4	4.0	4.9	0.154
Galactose	2.4	4.1	3.4	2.5	0.259
Glucose	7.2	10.2	5.4	1.7	0.580
Galacturonic acid	4.1	5.4	0.0	3.3	0.719
Total sNSP	45.7	59.9	38.6	32.7	0.265
iNSP					
Xylose	66.8	60.9	64.0	79.3	0.119
Arabinose	43.2	39.3	39.8	46.0	0.075
Mannose	6.8	6.1	6.2	9.3	0.211
Galactose	8.6	6.5	8.2	8.1	0.118
Glucose	63.4	62.0	60.6	77.1	0.116
Galacturonic acid	0.0	0.0	0.0	1.3	-
Total iNSP	188.8	174.8	178.8	221.0	0.110
Total NSP					
Xylose	82.0	83.9	78.3	88.3	0.050
Arabinose	54.3	52.2	51.3	57.2	0.049
Mannose	12.5	10.5	10.2	14.2	0.158
Galactose	11.0	10.6	11.6	10.6	0.043
Glucose	70.5	72.2	66.0	78.7	0.073
Galacturonic acid	4.1	5.4	0.0	4.7	0.683
Total NSP	234.5	234.7	217.5	253.7	0.063
Starch	41.5	28.0	35.0	88.1	0.565

289 sNSP = soluble NSP

290 iNSP = insoluble NSP

291 CV = coefficient of variation

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Table 5. *Dietary digestible energy (DE), apparent dietary ileal digestibility coefficients for protein (PD), dry matter (DMD) and fat (FD) when fed to laying hens from 22 to 23 weeks of age*

Treatment factor	DE (MJ/kg DM)	PD	DMD	FD
Digestibility coefficients				
Batch 1	11.44^{a}	0.697	0.667^{a}	0.656^{a}
Batch 2	12.41^{b}	0.766	0.777^{b}	0.785^{b}
Batch 3	12.15^{ab}	0.748	0.779^{b}	0.771^{b}
Batch 4	11.52^{a}	0.729	0.823^{b}	0.894^{c}
SEM	0.279	0.020	0.032	0.037
15% inclusion	11.95	0.745	0.692	0.688
30% inclusion	11.81	0.725	0.831	0.864
SEM	0.197	0.014	0.023	0.026
Batch 1 + 15%	11.58	0.706	0.543	0.523
Batch 2 + 15%	12.17	0.748	0.704	0.685
Batch 3 + 15%	12.08	0.755	0.695	0.669
Batch 4 + 15%	11.96	0.772	0.820	0.876
Batch 1 + 30%	11.30	0.687	0.786	0.788
Batch 2 + 30%	12.65	0.785	0.850	0.884
Batch 3 + 30%	12.23	0.741	0.862	0.872
Batch 4 + 30%	11.08	0.686	0.826	0.915
SEM	0.394	0.028	0.046	0.052
Probabilities of statistical differences				
Batch	0.048	NS	0.012	<0.001
Inclusion	NS	NS	<0.001	<0.001
Batch*Inclusion	NS	NS	NS	NS

There is a statistically significant difference when $P<0.05$; SEM – standard error of means (5% level). Means within a row with no common superscript differ significantly.

Table 6. *Dietary apparent ileal digestibility coefficients for indispensable amino acids when fed to laying hens from 22 to 23 weeks of age*

Treatment factor	Indispensable amino acids									
	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Try	Val
Digestibility coefficients										
Batch 1	0.657	0.615^{a}	0.597	0.635	0.526	0.715	0.685	0.490	0.586	0.565
Batch 2	0.709	0.679^{b}	0.664	0.689	0.604	0.757	0.733	0.570	0.693	0.631
Batch 3	0.680	0.654^{ab}	0.639	0.670	0.561	0.741	0.701	0.531	0.650	0.600
Batch 4	0.663	0.627^{ab}	0.615	0.646	0.549	0.724	0.680	0.501	0.645	0.575
SEM	0.016	0.016	0.018	0.017	0.024	0.015	0.014	0.022	0.020	0.019
15% inclusion	0.688	0.661	0.641	0.654	0.597	0.751	0.709	0.541	0.654	0.604
30% inclusion	0.666	0.626	0.617	0.666	0.524	0.717	0.691	0.505	0.634	0.581
SEM	0.011	0.011	0.013	0.012	0.017	0.010	0.010	0.016	0.014	0.013
Batch 1 + 15%	0.658	0.626	0.606	0.639	0.552	0.728	0.690	0.497	0.594^{a}	0.572
Batch 2 + 15%	0.656	0.604	0.588	0.631	0.500	0.702	0.719	0.483	0.579^{ab}	0.558
Batch 3 + 15%	0.695	0.678	0.646	0.675	0.605	0.754	0.710	0.572	0.658^{ab}	0.621
Batch 4 + 15%	0.723	0.680	0.672	0.702	0.604	0.760	0.717	0.569	0.729^{b}	0.641
Batch 1 + 30%	0.693	0.672	0.646	0.673	0.602	0.759	0.681	0.548	0.653^{ab}	0.608
Batch 2 + 30%	0.667	0.636	0.631	0.668	0.521	0.722	0.748	0.514	0.647^{b}	0.591
Batch 3 + 30%	0.707	0.669	0.654	0.678	0.628	0.762	0.692	0.548	0.653^{ab}	0.616
Batch 4 + 30%	0.618	0.585	0.576	0.614	0.469	0.685	0.642	0.454	0.580^{ab}	0.534
SEM	0.022	0.023	0.026	0.023	0.034	0.010	0.020	0.031	0.0141	0.027
Probability of statistical differences										
Batch	NS	0.038	NS	NS	NS	NS	0.051	NS	0.006	NS
Inclusion	NS	0.038	NS	NS	0.005	0.029	NS	NS	NS	NS
Batch*Inclusion	NS	NS	NS	NS	NS	NS	NS	NS	0.011	NS

There is a statistically significant difference when $P<0.05$; SEM – standard error of means (5% level). Means within a row with no common superscript differ significantly.

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Table 7. *Dietary apparent ileal digestibility coefficients for dispensable amino acids when fed to laying hens from 22 to 23 weeks of age*

Treatment factor	Dispensable amino acids							
	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
Digestibility coefficients								
Batch 1	0.545	0.528	0.511^{a}	0.787^{ab}	0.521^{a}	0.745^{a}	0.586	0.569
Batch 2	0.606	0.601	0.592^{b}	0.821^{b}	0.599^{b}	0.809^{b}	0.650	0.631
Batch 3	0.587	0.564	0.572^{ab}	0.802^{ab}	0.564^{ab}	0.786^{ab}	0.619	0.595
Batch 4	0.0567	0.542	0.535^{ab}	0.778^{a}	0.534^{ab}	0.752^{a}	0.590	0.578
SEM	0.0207	0.0193	0.0204	0.0092	0.0199	0.0113	0.0173	0.0199
15% inclusion	0.581	0.580	0.576	0.804	0.567	0.776	0.618	0.594
30% inclusion	0.571	0.538	0.529	0.790	0.542	0.770	0.604	0.592
SEM	0.0147	0.0136	0.0144	0.0065	0.0141	0.0080	0.0122	0.0141
Batch 1 + 15%	0.544	0.540	0.542	0.791	0.529	0.751	0.583	0.554
Batch 2 + 15%	0.545	0.516	0.479	0.783	0.513	0.738	0.589	0.583
Batch 3 + 15%	0.591	0.600	0.608	0.813	0.590	0.803	0.643	0.610
Batch 4 + 15%	0.621	0.603	0.576	0.829	0.608	0.815	0.656	0.651
Batch 1 + 30%	0.589	0.584	0.583	0.806	0.572	0.787	0.624	0.598
Batch 2 + 30%	0.584	0.543	0.562	0.798	0.556	0.785	0.614	0.591
Batch 3 + 30%	0.601	0.596	0.572	0.806	0.576	0.762	0.622	0.614
Batch 4 + 30%	0.534	0.489	0.498	0.750	0.491	0.743	0.558	0.541
SEM	0.0293	0.0136	0.0144	0.0065	0.0282	0.0080	0.0244	0.0281
Probability of statistical differences								
Batch	NS	0.058	0.035	0.013	0.042	<0.001	0.048	NS
Inclusion	NS	0.037	0.026	NS	NS	NS	NS	NS
Batch*Inclusion	NS	NS	NS	NS	NS	NS	NS	NS

There is a statistically significant difference when $P<0.05$; SEM – standard error of means (5% level). Means within a row with no common superscript differ significantly.

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