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Evaluation of the effect of different wheats and xylanase supplementation on performance, nutrient and energy utilisation in broiler chicks

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16Abstract

17The aim of this study was to evaluate the performance, nutrient utilisation and energy
18metabolism of broiler chicks fed eight different wheat samples, supplemented or not
19with xylanase. Seven-hundred sixty eight male broilers (1-day old) were distributed to
2016 experimental treatments (six replicates per treatment). The treatments were in a
21factorial arrangement with eight different wheats and two levels of xylanase (0 or
2216,000 BXU/kg). The predicted apparent metabolisable energy (AME) of the wheat
23samples ranged from 13.0 and 13.9 MJ/kg and all diets were formulated to contain the
24same amount of wheat. Body weight gain (BWG) and feed intake (FI) were measured at
2521 d, as was jejunal digesta viscosity, and feed conversion ratio (FCR) calculated. On
26day 24, one representative bird pen was selected to calculate whole body energetics. At
2721 d, three chicks per replicate were randomly allocated to metabolism cages for energy
28and nutrient utilisation determinations, and were continued on the experimental diets
29until 24-d-old. No interactions were observed for any performance response variables,
30ileal nutrient utilisation or digesta viscosity. Xylanase improved BWG and reduced FCR
31and digesta viscosity ($P < 0.05$). Wheat influenced dry matter (DM) utilisation and
32xylanase increased ileal digestible energy ($P = 0.04$). Xylanase also improved ($P <$
330.05) DM and nitrogen retention. Apparent metabolisable energy and AME corrected
34for nitrogen (AMEn) were subject to an interaction whereby wheats 2 and 6, which
35returned the lowest AME and AMEn values, responded to xylanase supplementation
36and the remainder did not. Net energy for production and the efficiency of energy use
37for production were not influenced by xylanase, but were affected by wheat ($P < 0.05$).
38Despite the significant differences between wheats with regards to their nutrient
39utilisation and energy metabolism in birds, xylanase removed this variance and resulted
40in more homogeneous performance.

41Keywords: Wheat, Near-infrared spectroscopy, Xylanase, Animal performance, Nutrient

42release, energy, Broiler chickens

1. Introduction

Variation in the nutritive value of wheat samples is a reflection of genetic and environmental effects, and the economic impact of these variations on poultry performance highlights the need for improved predictors of wheat quality (Yegani and Korver 2012). This is a concern for plant breeders, farmers and animal nutritionists. Thus, nutritionists need to know the nutritional requirements of commercial poultry, and be able to determine or predict the nutritive value of each batch of raw material in an accurate and timely manner (van Kempen and Simmins 1997).

The use of Near-Infrared Spectroscopy (NIRS) provides an opportunity to determine the chemical composition of feedstuffs and their nutritive value before inclusion in the diet (Olukosi et al., 2011; Owens et al., 2009). The information from NIRS can be used to reduce or minimize nutrient imbalances in commercial rations fed to the animals. However, there are potential errors associated with NIRS technology such as sample-related and chosen reference method errors which can lead to high values for coefficient of variation (Yegani and Korver 2012), and as a result care must be taken in establishing NIRS calibration to ensure it is robust, precise and accurate. Near-Infrared Spectroscopy calibrations now exist which can predict non-starch polysaccharide (NSP) and energy contents of wheat. In particular xylans, is often considered an anti-nutrient in wheat, and as a result variation in content of this component between wheat samples may contribute to differences in nutritive value. Xylanases are the major enzymes involved in arabinoxylan degradation, hydrolysing the 1,4-β-D-xylosidic linkage between xylose residues in the backbone in a random manner (Mendis et al. 2016), therefore it is hypothesised that their supplementation in poultry feed may balance animal performance although differences in the nutritive value of different wheat origins. This work was undertaken to determine if such a calibration by NIRS accurately predicts

animal performance, and if so whether the application of an NSP-degrading xylanase would reduce the performance differences between samples of wheat which differ in NSP content (Bedford, 2000).

2. Materials and Methods

All the experimental procedures received prior approval from the Scotland's Rural College's Animal Experiment Committee.

2.1. Birds and experimental design

A total of 768 one-day old male broiler chicks (Ross 308) obtained from a commercial hatchery were used in the study for two experiments to determine growth performance and whole-body energy metabolism (Exp. 1) and nutrient utilisation (Exp. 2) responses. For Exp. 1 (n = 768) and for Exp. 2 (n = 288), birds were allocated to 16 experimental treatments in a randomized complete block design with an 8 × 2 factorial arrangements of treatments (eight wheat samples and two levels of xylanase), having in both experiments six replicates per treatment. Throughout the study, feed and water were supplied *ad libitum* and animals were raised under controlled conditions of light and temperature, as breeder recommended.

2.1.1. Experiment 1

Birds were reared up to day 24 in floor pens. All broiler chickens and feed were weighed on day 0 and 21 to calculate growth performance responses: body weight gain (BWG), feed intake (FI) and feed conversion ratio (FCR). On day 21, two chickens were randomly selected and euthanized by an overdose of sodium pentobarbital and jejunal digesta were collected for viscosity measurement. On day 24, one representative bird (on BW basis) per floor pen was selected and fasted prior to euthanasia to calculate the whole body energetics.

2.1.2. Experiment 2

On day 21, three chicks were randomly selected from each of the 96 floor pens and transferred to 96 metabolism cages (for energy and nutrient utilisation trial) where chickens continued to receive the corresponding diets until 24 days of age. Excreta and ileal digesta were collected on day 24 and pooled on a cage basis for calculation of nutrient utilisation.

2.2. Diets and wheat selection

Starter experimental diets based on wheat and soybean-meal were formulated to be marginally lower in metabolisable energy (ME) than Ross 208 requirements (Table 1). Eight wheat samples originating from Germany and United Kingdom were obtained. Dry matter (DM), gross energy (GE), fat, nitrogen (N), calcium (Ca) and the phosphorous (P) contents of wheat samples were chemically analysed and further NIRS analyses were performed (Tables 2 and 3). A fixed amount of each wheat (58.6%) was used in the formula regardless of their chemical composition. Diets were predicted to

contain 12.8 ME MJ/kg based on assumed average wheat apparent ME (AME) 58.6% came from wheat grain. Control diets were supplemented with 16,000 BXU/kg of xylanase following supplier recommendations (Econase XT, AB Vista, Marlborough, UK; 160,000 BXU/g), resulting in 16 experimental diets in total. All diets contained phytase supplemented at 500 FTU/kg (Quantum Blue, AB Vista, Marlborough, UK; 5000 FTU/g). Activity of xylanase and phytase were determined using the reference method of analysis recommended by the supplier. Titanium dioxide (0.3%) was added to all the diets as an indigestible marker. Feed samples were taken at the beginning and throughout the experimental period for DM, N, fat and GE analysis.

2.3. Jejunal viscosity

Approximately 1.5 g (wet weight) of the fresh jejunal digesta were analysed according to Bedford et al. (1991). The viscosity (expressed as centipoise units, cP = 1/100 dyne sec/cm^2) was determined using a Brookfield DV II digital viscometer.

2.4. Nutrient utilisation and total tract retention

Total tract retention and ileal nutrient utilisation were calculated using the index method (Olukosi et al., 2007), with titanium dioxide as the indigestible marker.

2.5. Net energy and nutrient accretion

Net energy for production (NEp), heat production (HP) and carcass fat and protein accretion were determined using the comparative slaughter technique as described by

142Olukosi et al. (2008). Briefly, six birds were euthanized at day 0 without feeding and
143kept frozen prior to processing and chemical analyses. On day 24, following euthanasia
144the carcasses were frozen and ground prior to freeze drying. Gross energy, N and fat
145contents were analysed. All the calculations for NEp, ME intake, HP as well as the
146efficiencies of energy for fat and protein retention (Fat-ER and CP-ER, respectively) are
147as described previously (Olukosi et al., 2008a). Net energy for production and HP were
148expressed per kg feed by dividing the total NEp (MJ) or HP (MJ) by kilogram of feed
149intake.
150
1512.6. Chemical analyses
152
153Ileal digesta and excreta were analysed for DM, N, fat and GE. Dry matter was
154determined by drying the samples in a drying oven (Uniterm, Russel-Lindsey
155Enginering Ltd., Birmingham, England, UK) at 105 ℃ for 24 h (method 934.01;
156AOAC, 2006). Total N content was determined by the combustion method (method
157968.06; AOAC, 2006). Gross energy was determined in an adiabatic oxygen bomb
158calorimeter (model 6200; Parr Instruments, Moline, IL) using benzoic acid as an
159internal standard. Titanium concentration in samples of diets and ileal digesta was
160determined using the method of Short et al. (1996).
161
1622.7. Statistical analyses
163
164Pen served as the experimental unit for FI, BWG and FCR, and cages as experimental
165unit for nutrient utilisation, jejunal viscosity, net energy and nutrient accretion. Data
166were analysed using the PROC MIXED command of SAS (SAS Inst. Inc., Cary, NC).

When effects were found to be significant, treatment means were separated using Tukey's Highly Significant Difference test. Statistical significance was accepted at $P < 0.05$ and trends were discussed at $P < 0.10$.

3. Results

3.1. Wheat nutritive value by NIRS and chemical analyses

The chemical analysis of the wheat samples indicates that they are all very similar in chemical composition and GE (Table 2). The predicted nutritive values by NIRS showed slightly more variability in nutrient composition between wheat varieties (Table 3), but remained close to expected average values. The predicted GE was underestimated while the predicted fat content was higher than chemically analysed. The predicted AME of wheat varieties ranged from 13.0 to 13.9 MJ/kg (CV < 2%). There was a great deal of variability (CV > 10%) in the predicted contents for crude protein, acid detergent fibre, β-glucan, lignin and total non-starch polysaccharides, but low variability (CV < 8%) in all other analysed chemical components, including amino acids.

3.2. Feed enzyme activity, growth performance and jejunal viscosity

Enzyme activities in feed samples were close to expected (16,038 BXU/kg average value analysed in all the xylanase-supplemented diets). No interactions were observed in any of the performance parameters measured (Table 4). There were no effects of wheat on performance or jejunal digesta viscosity. Nevertheless, improvements in

performance were observed when xylanase was supplemented, regardless of wheat sample. Xylanase application resulted in a near significant 20 g (P = 0.077) increase in BWG. Although FI was not influenced by xylanase, FCR was significantly improved by four points better (1.33 vs. 1.37, xylanase vs. control, respectively; P = 0.003). Xylanase supplementation also reduced viscosity of jejunal digesta (3.32 vs. 2.34 cP, for control and xylanase supplemented diets, respectively; P < 0.001). In the diets without xylanase supplementation, there were low and non-significant correlations between nutrient content of the wheats and bird FCR (Table 5). For the birds receiving xylanase supplemented diets, FCR was positively correlated with the analysed P and the predicted contents by NIRS of NDF, total and soluble AX as well as insoluble NSP. In addition, FCR was positively correlated with the analysed fat content.

3.3. Nutrient utilisation and total tract retention

No interactions between the main factors were observed for any of the ileal nutrient utilisation results (Table 6). The DM utilisation of wheat 3 was significantly lower compared with wheats 6, 7 and 8 (P < 0.05), whereas wheats 1, 2, 4 and 5 had intermediate values. Wheats 7 and 8 had greater energy utilisation (P < 0.001) compared with wheats 1, 2, 3 and 5, whereas wheats 4 and 6 where in between. Xylanase supplementation increased ileal utilisation of energy (IDE) measured as MJ/kg (P = 0.04), regardless of wheat. Ileal N utilisation tended to be influenced by wheat (P = 0.06), and was not influenced by xylanase supplementation.

There were significant interactions of the main factors for all total tract measurements (P < 0.001). Xylanase supplementation improved the retention of DM and N as well as AME and AMEn for diets based on wheats 2 and 6. For those diets based on wheats 3,

4, 5 and 8 xylanase, inclusion led to no effect or marginally lower results in total tract retention of N, AME and AMEn.

3.4. Net energy and nutrient accretion

There were no interactions between wheat and xylanase for any energy utilisation and efficiency responses, except for HP and Kre-protein, and no xylanase effect on any of the responses (Table 8). Net energy for production and K_{RE} were greater ($P < 0.05$) for wheat 2 compared with wheats 4, 5 and 7, but similar, although numerically higher, than the other wheats. Energy retained as protein was greater ($P < 0.05$) for wheats 3, 4 and 5 compared with wheats 7 and 8. Energy retained as fat and Kre-fat was greater ($P < 0.05$) for wheat 2 than wheats 1, 3, 4 and 5. The interaction observed for HP ($P = 0.02$) was explained by xylanase supplementation increasing HP when birds were fed wheats 2 and 6 (data not shown), but decreased HP for wheat 8, with no effect observed for the remaining wheats. The interaction noted for Kre-protein ($P = 0.006$; data not shown) was due to xylanase addition resulting in birds fed wheats 3 and 8 supplemented being more efficient in protein accretion, whereas it was reduced for wheats 2 and 6, with no effect on the remaining wheats.

4. Discussion

It is well known that wheats, even of the same variety, can vary in both chemical composition and nutritive value (Theander et al., 1989). The current study investigated the effect of wheat sample and xylanase supplementation on the performance of broilers fed starter diets. In spite of the variability found between wheats in both the analysed

chemical composition and that predicted by NIRS, performance was not affected. Nevertheless, supplementation with xylanase improved BWG, FCR and reduced digesta viscosity, as has been shown in numerous studies (Olukosi et al., 2007; Wu et al., 2004; Zyla et al., 1999). Arabinoxylan is the main NSP in cereals, representing about 60-70% in the cell wall endosperm cells an aleurone layer. Although AX from different sources differs in their substitution along the xylan backbone, a general structure can be assigned for AX: a backbone of β-(1,4)-linked xylose residues, which are substituted with arabinose residues on the C(O)-2 and/or C(O)-3 position and phenolic acids can be linked on the C(O)-5 position of arabinose. The structure of AX leads to high water holding capacity in the gastrointestinal tract resulting in high viscosity, and as a consequence animal production process is less efficient. Xyalanases cleave AX by internally hydrolysing the β-1,4-β-D-xylosidic linkage between xylose residues giving small fragments of oligosaccharides with high or low degree of substitution (Mendis et al. 2016). The successful exposure of xylanase to different wheats with variations in the level content of soluble NSP makes them a feasible choice to mitigate the negative effects of arabinoxylan (AX) in monogastrics (Bedford 2000).

Feed conversion ratio was not correlated with any of the analysed or predicted composition values of wheat without xylanase, but those supplemented with the enzyme had an unexpected positive correlation with the predicted contents of fat and fibre components (NDF, AX, soluble AX and total insoluble NSP). These findings are puzzling and suggest that the presence of more fibre (substrate) when the enzyme is present resulted in poorer performance but that the presence of this fibre in the absence of the enzyme was, if anything, marginally beneficial. Scott et al. (1999) found a

significant relationship between predicted AME and FCR in wheat based diets with enzymes (r = -0.46), similarly found in this study (r = -0.45).

Non-starch polysaccharide degrading enzymes reduce digesta viscosity in the animal by shortening the molecular weight of NSP and also partly remove the nutrient encapsulation effect of the cell wall components and, as a consequence, nutrient absorption is promoted and growth performance maximized (Masey O'Neill et al., 2012, 2014a,b; Persia et al., 2002). In this study the measured intestinal viscosity of all samples was extremely low in comparison with the literature, which suggests that the wheat samples employed were not particularly challenging from a viscosity viewpoint. In a similar study, xylanase supplementation improved performance in broilers fed different Chinese maize samples varying in chemical composition, improving the homogeneity in animal flocks with NSP-ases addition (Masey O'Neill et al., 2012).

Some studies have reported improved performance and energy utilisation when NSP-enzymes are used in diets based on wheat, rye, barley (Bedford and Morgan, 1996; Bedford and Schulze, 1998) or maize (Masey O'Neill et al., 2012), but other studies have only shown improvements in animal performance without changes in nutrient utilisation (Hong et al., 2002; Wu et al., 2004). Wheat sample influenced ileal DM, N, energy utilisation and IDE. In particular, wheats 6, 7 and 8 were particularly good samples and this coincided with wheats 7 and 8 having the lowest viscosity. On the other hand, wheats 6, 7 and 8 also had lower contents of N (and predicted crude protein), acid detergent fiber, AX and NSP compared with the other wheats. Xylanase use increased energy utilisation and AME. Aside from the effect of reducing viscosity, there may be an additional benefit of increasing the permeability of the aleurone layer.

This may enhance contact with digestive enzymes and their substrates, for better nutrient utilisation (Parkkonen et al., 1997).

The interaction of the main factors for all total tract measures of nutrient utilisation was significant. This was mostly due to the large responses of wheats 2 and 6 to xylanase addition due to their comparatively low nutrient utilisation in the absence of enzyme. Feed conversion ratio and measured AME significantly correlated in both wheats, suggesting the added benefit (r = -0.65, $P = 0.023$ and r = -0.49, $P = 0.11$, respectively; data not shown). This observation implies that xylanase may have greater effects in poorer quality samples, elevating their nutritive value and thus reducing the variability between samples. Nonetheless, none of the results from the chemical analysis or NIRS predictions suggested that these two samples may have had a poorer nutritive value than the others. In this regard, it is noteworthy the low correlation between the predicted AME and the measured AME (r = -0.16; $P = 0.13$) suggesting the limited capacity of NIR to predict animal performance (data not shown). Wheats 3, 4, 5 and 8 had higher nutrient utilisation in the absence of enzyme, which may be due to the presence of endoxylanase in the outer layer of wheat (Cleemput et al., 1997), being responsible for part of the degradation of AX (Dornez et al., 2006), or lesser content of xylanase inhibitors or both.

The response of broilers to dietary intervention in general and enzyme supplementation in particular is usually measured using growth performance responses or ileal nutrient utilisation and total tract nutrient retention. These can be adequate for measuring gross efficiency of nutrient utilisation, but to further characterize the efficiency of nutrient utilisation it is important to delineate the weight gain into the composition of gain, i.e.,

316protein or fat, especially because of the differences in the efficiency with which these
317nutrients are deposited (Olukosi and Adeola, 2008). Net energy for production can be
318used as a more sensitive measure of energy utilisation by chickens receiving exogenous
319enzymes because it takes into account the efficiency of utilisation of ME for growth
320(Bhuiyan and Iji, 2015; Pirgozliev and Rose, 1999; Olukosi and Adeola, 2008; Olukosi
321et al., 2008a). Net energy for production is not only dependent on body weight but also
322on the amount of energy deposited in the carcass, which is an indication of how
323effectively the enzyme used facilitated energy utilisation. Net energy for production and
324K_{RE} were not influenced by xylanase supplementation, but wheat sample did. Wheat
325samples 2, 7 and 8 presented better indices of energy utilisation, which may be related
326to the fact that they have the lowest viscosities compared with the other wheats. Heat
327production and Kre-Protein varied depending on wheat and xylanase inclusion.
328
329Interestingly, xylanase supplementation of wheats 2 and 6 increased total tract AME
330retention, Nep and HP but reduced K_{RE}, Kre-CP and Kre-Fat and the efficiency of
331energy use for protein and fat accretion, as has been demonstrated previously (Bhuiyan
332and Iji, 2015; Daskiran et al., 2004; Olukosi and Adeola, 2008; Olukosi et al., 2008a). In
333the current study, the comparison between animal performance and energy utilisation
334must be considered with caution as only one bird from each replicate was selected. The
335extrapolation of the performance data derived from eight animals per replicate may thus
336have some mis-alignment with the energy utilisation results obtained from one
337individual bird.
338
339The utilisation of ME was more efficient for energy deposition and less for protein and
340fat. Nevertheless the efficiency of protein accretion was almost two-fold that of fat

accretion, which was similarly shown by previous authors (Olukosi and Adeola, 2008; Olukosi et al., 2008b). The genetics and age of birds are important factors (Leeson and Summers, 1997; Lopez and Leeson, 2005). The higher proportion and retention of protein than fat is likely because the young broiler chicks were still actively growing and have not reached the stage at which fat deposition can overtake protein deposition (Bregendahl et al., 2002; Sanz et al., 2000).

5. Conclusion

Under the current experimental conditions xylanase supplementation may compensate for the poorer nutritive value of some wheats, enabling more homogenous broiler chick performance. Unfortunately the predicted nutrient composition by NIR did not predict accurately animal performance, and moreover taken together the predicted nutrient and chemically determined contents of the wheats used in this study did not allow for accurate ranking of the samples prior to feeding, which may relate to the very low viscosity of the wheat samples employed. In this regard, the use of the xylanase as an insurance policy is justified.

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Conflict of interests

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367All authors declare no conflict of interests.

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462

463Tables

464Table 1 Ingredient and calculated composition as-fed of the experimental diets

Item	Control	+ Xylanase
Ingredient, g/kg		
Wheat - feed	585	585
Soybean meal 48	325	325
Soy oil	44.4	44.4
Salt	3.00	3.00
Sodium bicarbonate	1.87	1.87
DL-methionine	2.99	2.99
Lysine HCl	2.46	2.46
Threonine	0.77	0.77
Limestone	7.86	7.86
Dicalcium phosphate	15.5	15.5
Vitamin premix[1]	4.90	4.90
Phytase[2]	+	+
Xylanase[3]	-	+
Calculated nutrient composition, %		
Crude protein	22.4	22.4
Ca	0.90	0.90
P	0.74	0.74
Available phosphorous	0.45	0.45
Fat	5.72	5.72
Fibre	2.55	2.55
Met	0.62	0.62
Cys	0.38	0.38
Met + Cys	1.00	1.00
Lys	1.35	1.35
His	0.55	0.55
Trp	0.28	0.28
Thr	0.88	0.88
Arg	1.45	1.45
Ile	0.92	0.92
Leu	1.64	1.64
Phe	1.05	1.05
Val	1.00	1.00
AME, MJ/kg	12.8	12.8

465AME = apparent metabolisable energy.

466[1] Vitamin/mineral premix supply per kilogram of diet: vitamin A, 16,000 IU; vitamin

467D_3, 3000 IU; vitamin E, 25 IU; vitamin B_1, 3 mg; vitamin B_2, 10 mg; vitamin B_6, 3 mg;

468vitamin B_{12}, 15 µg; nicotinic acid, 60 mg; pantothenic acid, 14.7 mg; folic acid, 1.5 mg;

469biotin, 125 µg; choline chloride, 25 mg; Fe as iron sulfate, 20 mg; Cu as copper sulfate,

47010 mg; Mn as manganous oxide, 100 mg; Co as cobalt oxide, 1.0 mg; Zn as zinc oxide,

47182.222 mg; I as potassium iodide, 1 mg; Se as sodium selenite, 0.2 mg; and Mo as

472molybdenum oxide, 0.5 mg.

473[2] Quantum Blue 5G, AB Vista, Marlborough, UK; 5000 FTU/g.

474[3] Econase XT 25P, AB Vista, Marlborough, UK; 160,000 BXU/g.

475Table 2 Analysed nutrient composition and coefficient of variation (CV) of the wheat

476samples

Item	Wheat samples								
	1	2	3	4	5	6	7	8	CV
Gross energy, MJ/kg	18.0	18.1	18.1	18.0	18.2	17.9	18.0	18.1	<1
Viscosity, cP	10.5	8.50	12.8	13.0	11.3	11.2	7.60	7.80	21
Dry matter, %	87.2	87.4	87.8	87.5	87.1	87.2	88.6	87.6	<1
Fat, %	1.49	1.37	1.48	1.37	1.26	1.15	1.24	1.94	17
Nitrogen, %	2.22	1.88	2.37	2.10	2.02	1.79	1.55	1.79	13
Calcium, %	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.05	31
Phosphorous, %	0.28	0.32	0.34	0.33	0.38	0.29	0.27	0.33	11
Phytic acid, %	0.75	0.77	0.64	0.72	0.81	0.92	0.53	0.53	19

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479Table 3 Nutrient composition predicted by near-infrared spectroscopy (NIRS) and

480coefficients of variation (CV) of the wheat samples

Item	Wheat samples								
	1	2	3	4	5	6	7	8	CV
Energy, MJ/kg and ether extract, %									
GE	16.5	16.5	16.6	16.6	16.6	16.4	16.3	16.4	<1
AME	13.4	13.4	13.2	13.0	13.3	13.6	13.9	13.4	2
Fat	2.10	2.23	2.16	2.40	2.28	2.25	1.95	2.13	6
Fibre									
NDF	15.1	16.4	16.1	19.0	17.2	16.1	14.0	16.1	9
ADF	2.44	2.82	2.94	3.94	3.15	2.99	2.11	3.02	18
Lignin	0.72	0.97	0.89	1.15	1.06	1.02	0.95	0.94	13
AX	7.66	8.10	7.97	9.19	8.48	7.83	7.30	8.02	7
Soluble AX	0.56	0.61	0.57	0.62	0.63	0.59	0.58	0.57	4
β-glucan	1.21	1.66	1.66	2.36	1.88	1.63	1.78	1.90	18
Total insoluble NSP	10.2	11.4	11.1	13.2	12.1	11.1	10.4	11.3	8
Total soluble NSP	1.84	2.47	2.36	3.23	2.75	2.43	2.56	2.64	15
Protein,% and amino acid profile, g/100 g CP									
CP	13.4	11.44	13.6	11.7	11.9	10.6	8.36	10.2	15
Lysine	3.01	3.35	2.96	3.42	3.26	3.18	3.07	3.19	5
Methionine	1.56	1.68	1.60	1.65	1.69	1.70	1.78	1.67	4
Leucine	7.37	6.64	7.07	6.47	6.43	6.98	7.22	7.10	5
Threonine	3.30	3.42	3.25	3.42	3.34	3.41	3.41	3.42	2
Tryptophan	1.16	1.21	1.16	1.21	1.19	1.22	1.30	1.27	4
Tyrosine	3.21	3.13	3.20	3.09	3.12	3.23	3.28	3.23	2
Valine	4.75	4.91	4.76	4.96	4.86	4.90	4.99	4.95	2
Phenylalanine	4.43	4.39	4.55	4.53	4.47	4.44	4.53	4.50	1
Histidine	2.57	2.62	2.59	2.61	2.63	2.62	2.60	2.58	<1
Isoleucine	3.48	3.43	3.53	3.45	3.46	3.47	3.46	3.46	<1
Arginine	5.18	5.43	5.09	5.52	5.33	5.07	4.54	4.99	6
Alanine	4.28	3.76	4.11	3.89	3.67	4.04	4.33	4.22	6
Asparagine	6.06	6.22	5.79	6.27	5.98	6.04	5.59	6.00	4
Cysteine	2.19	2.34	2.20	2.27	2.34	2.33	2.40	2.32	3
Glutamine	24.9	23.5	26.0	23.2	24.7	24.1	24.0	23.4	4
Glycine	3.99	4.27	3.98	4.19	4.23	4.22	4.19	4.15	3
Proline	9.23	8.99	9.78	9.23	9.39	9.28	9.91	9.40	3
Serine	4.88	4.83	4.83	4.70	4.79	4.84	4.81	4.78	1

GE= gross energy; AME = apparent metabolisable energy; NDF = neutral detergent fibre; ADF = acid detergent fibre; AX = arabinoxylan; NSP = non-starch polysaccharides; CP = crude protein.

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507Table 4 Animal performance and jejunal digesta viscosity[1]

Item	Weight gain, g/bird	Feed intake, g/bird	Feed conversion ratio, g/g	Jejunal viscosity, cP
Wheat effect				
1	824	1105	1.341	2.81
2	816	1103	1.353	3.13
3	820	1087	1.329	2.89
4	817	1097	1.345	3.01
5	781	1087	1.394	2.77
6	791	1079	1.369	2.94
7	787	1049	1.341	2.40
8	791	1065	1.349	2.67
SEM	16	16	0.019	0.06
Xylanase effect				
0 BXU/kg	793[b]	1088	1.373[a]	3.32[a]
16,000 BXU/kg	813[a]	1079	1.331[b]	2.34[b]
SEM	8	8	0.010	0.03
P-value				
Wheat	0.465	0.192	0.367	0.380
Xylanase	0.072	0.496	0.003	<0.001
Interaction	0.951	0.950	0.894	0.845

508[a,b]Means in the same column with different letters differ at $P < 0.05$.

509[1] Mean values for six replicate cages with eight broilers per replicate cage.

Table 5 Correlation of feed conversion ratio (FCR) with the analysed chemical composition and the predicted values by near-infrared spectroscopy (NIRS) of wheat in diets supplemented with or without xylanase

Item	Pearson's Correlation coefficients with FCR	
	Without xylanase	With xylanase
Analysed composition		
GE	-0.27	0.38
Fat	0.14	-0.26
Nitrogen	-0.47	0.07
Calcium	-0.43	0.36
Phosphorous	-0.35	0.70*
NIRS predicted composition		
CP	0.06	0.07
Fat	-0.27	0.68*
GE	-0.09	0.49
AME	0.53	-0.45
ADF	-0.34	0.63
NDF	-0.31	0.69*
Total AX	-0.36	0.73*
Soluble AX	0.25	0.85*
β-glucan	-0.34	0.55
Lignin	0.07	0.62
Total insoluble NSP	-0.26	0.74*
Total soluble NSP	-0.23	0.60

GE = gross energy; NIRS = near-infrared spectroscopy; CP = crude protein; AME = apparent metabolisable energy; ADF = acid detergent fibre; NDF = neutral detergent fibre; AX = arabinoxylan; NSP = non-starch polysaccharides.

*$P < 0.05$

517Table 6 Ileal nutrient utilisation of nutrients[1]

Item	Dry matter, %	Nitrogen, %	Energy, %	IDE, MJ/kg
Wheat effect				
1	68.0^{bc}	78.0	70.8^{bc}	13.2^{b}
2	66.9^{bc}	74.8	70.0^{c}	13.1^{b}
3	65.2^{c}	74.4	69.5^{c}	13.2^{b}
4	68.8^{bc}	78.2	72.0^{abc}	13.7^{ab}
5	66.9^{bc}	75.9	69.6^{c}	13.0^{b}
6	70.2^{ab}	78.1	73.2^{abc}	13.8^{ab}
7	70.4^{ab}	79.4	73.9^{ab}	14.0^{a}
8	73.0^{a}	79.7	76.0^{a}	14.4^{a}
SEM	1.47	1.42	1.47	0.28
Xylanase effect				
0 BXU/kg	67.8	76.9	70.9 ^{b}	13.35 ^{b}
16,000 BXU/kg	69.5	77.8	72.9 ^{a}	13.77 ^{a}
SEM	0.74	0.71	0.74	0.14
P-value				
Wheat	0.012	0.062	0.019	0.004
Xylanase	0.111	0.205	0.057	0.039
Interaction	0.550	0.104	0.571	0.577

518IDE = ileal utilization of energy.

519^{a-c} Means in the same column with different letters differ at $P < 0.05$.

520[1]Mean values for six replicate cages with eight broilers per replicate cage.

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524Table 7 Total tract retention of nutrients[1]

Wheat & Xylanase effect		Dry matter, %	Nitrogen, %	AME, MJ/kg	AMEn, MJ/kg
Wheat	Xylanase, BXU/kg				
1	0	69.4^{cde}	62.9^{de}	13.5^{ef}	13.0^{e}
1	16,000	71.2^{bc}	60.7^{ab}	14.1^{cde}	13.5^{cd}
2	0	65.4^{g}	57.9^{f}	12.9^{h}	12.4^{g}
2	16,000	73.4^{a}	65.7^{a}	14.5^{ab}	14.0^{ab}
3	0	68.6^{de}	58.1^{cd}	13.8^{fg}	13.2^{e}
3	16,000	68.4^{e}	57.4^{cd}	13.8^{fg}	13.2^{ef}
4	0	71.5^{abc}	63.3^{abc}	14.2^{abc}	13.8^{abc}
4	16,000	70.6^{cd}	62.7^{cd}	14.1^{cd}	13.6^{cd}
5	0	69.6^{cde}	64.6^{e}	13.5^{def}	13.0^{de}
5	16,000	66.1^{fg}	57.7^{ef}	13.0^{gh}	12.4^{fg}
6	0	65.2^{g}	55.1^{ef}	13.0^{h}	12.4^{g}
6	16,000	73.1^{ab}	66.9^{abc}	14.4^{ab}	13.9^{ab}
7	0	68.0^{ef}	62.0^{ef}	13.6^{fg}	13.1^{ef}
7	16,000	69.9^{cde}	65.3^{e}	14.1^{ef}	13.7^{e}
8	0	72.8^{ab}	65.8^{abc}	14.5^{a}	14.0^{a}
8	16,000	71.4^{abc}	64.1^{abc}	14.2^{bc}	13.7^{bc}
Pooled SEM		0.73	0.79	0.12	0.12
P-value					
Wheat		<0.001	<0.001	<0.001	<0.001
Xylanase		<0.001	<0.001	<0.001	<0.001
Interaction		<0.001	<0.001	<0.001	<0.001

525AME = apparent metabolisable energy; AMEn = AME corrected for nitrogen ;

526[a-e] Different letters mean significant differences between treatments, highlighting the

527statistical interaction between main factors wheat x xylanase ($P < 0.05$).

528 [1]Mean values for six replicate cages with three broilers per replicate cage.

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534Table 8 Energy utilisation, energy retained and efficiencies of energy use[1]

Item	Energy utilisation, MJ/kg		Energy retained, MJ/kg		Efficiencies of energy use for energy, protein and fat retention accretion		
	Nep[2]	HP[3]	Protein-ER[4]	Fat-ER[5]	K_{RE}[6]	Kre-Protein[7]	Kre-Fat[8]
Wheat effect							
1	5.59^{abc}	6.84^{bc}	3.92^{ab}	2.20^{bc}	0.45^{bc}	0.275^{ab}	0.154^{abcd}
2	5.94^{a}	6.35^{d}	3.89^{ab}	2.48^{a}	0.48^{a}	0.275^{ab}	0.175^{a}
3	5.53^{abc}	6.54^{cd}	3.94^{a}	2.04^{c}	0.46^{ab}	0.289^{a}	0.149^{bcd}
4	5.53^{c}	7.24^{a}	3.95^{a}	2.04^{c}	0.43^{c}	0.269^{bc}	0.139^{d}
5	5.32^{c}	6.74^{bc}	3.96^{a}	2.05^{c}	0.44^{bc}	0.277^{ab}	0.143^{cd}
6	5.64^{abc}	6.60^{bcd}	3.89^{ab}	2.24^{abc}	0.46^{ab}	0.275^{ab}	0.158^{abcd}
7	5.72^{bc}	6.44^{bcd}	3.83^{b}	2.25^{abc}	0.47^{b}	0.278^{ab}	0.163^{ab}
8	5.77^{ab}	7.22^{ab}	3.84^{b}	2.41^{ab}	0.44^{bc}	0.258^{c}	0.162^{abc}
SEM	0.135	0.155	0.031	0.098	0.011	0.0050	0.0078
Xylanase effect							
0 BXU/kg	5.54	6.68	3.92	2.18	0.454	0.275	0.153
16,000 BXU/kg	5.72	6.81	3.89	2.24	0.457	0.274	0.158
SEM	0.068	0.077	0.016	0.049	0.005	0.0025	0.0039
P-value							
Wheat	0.029	0.001	0.032	0.008	0.012	0.017	0.029
Xylanase	0.950	0.060	0.135	0.373	0.327	0.869	0.354

Interaction	0.198	0.018	0.429	0.922	0.284	0.006	0.984

[1]Mean values for six replicate cages with one broiler per replicate cage.

[2] NEp - net energy for production.

[3] HP - heat production.

[4] Protein-ER - energy retained as protein.

[5] Fat ER - energy retained as fat.

[6] K_{RE} - efficiency of energy use for production.

[7] Kre-Protein - efficiency of energy use for protein accretion.

[8] Kre-Fat - efficiency of energy use for fat accretion.

[a-d] Means in the same column with different letters differ at $P < 0.05$.