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

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1Evaluation of the effect of different wheats and xylanase supplementation on  
2performance, nutrient and energy utilisation in broiler chicks

3

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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

### 431. Introduction

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

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

68animal performance, and if so whether the application of an NSP-degrading xylanase  
69would reduce the performance differences between samples of wheat which differ in  
70NSP content (Bedford, 2000).

71

72

## 732. Materials and Methods

74

75All the experimental procedures received prior approval from the Scotland's Rural  
76College's Animal Experiment Committee.

77

### 782.1. Birds and experimental design

79

80A total of 768 one-day old male broiler chicks (Ross 308) obtained from a commercial  
81hatchery were used in the study for two experiments to determine growth performance  
82and whole-body energy metabolism (Exp. 1) and nutrient utilisation (Exp. 2) responses.  
83For Exp. 1 ( $n = 768$ ) and for Exp. 2 ( $n = 288$ ), birds were allocated to 16 experimental  
84treatments in a randomized complete block design with an  $8 \times 2$  factorial arrangements  
85of treatments (eight wheat samples and two levels of xylanase), having in both  
86experiments six replicates per treatment. Throughout the study, feed and water were  
87supplied *ad libitum* and animals were raised under controlled conditions of light and  
88temperature, as breeder recommended.

89

#### 902.1.1. Experiment 1

91

92Birds were reared up to day 24 in floor pens. All broiler chickens and feed were  
93weighed on day 0 and 21 to calculate growth performance responses: body weight gain  
94(BWG), feed intake (FI) and feed conversion ratio (FCR). On day 21, two chickens  
95were randomly selected and euthanized by an overdose of sodium pentobarbital and  
96jejunal digesta were collected for viscosity measurement. On day 24, one representative  
97bird (on BW basis) per floor pen was selected and fasted prior to euthanasia to calculate  
98the whole body energetics.

99

#### 1002.1.2. Experiment 2

101

102On day 21, three chicks were randomly selected from each of the 96 floor pens and  
103transferred to 96 metabolism cages (for energy and nutrient utilisation trial) where  
104chickens continued to receive the corresponding diets until 24 days of age. Excreta and  
105ileal digesta were collected on day 24 and pooled on a cage basis for calculation of  
106nutrient utilisation.

107

#### 1082.2. Diets and wheat selection

109

110Starter experimental diets based on wheat and soybean-meal were formulated to be  
111marginally lower in metabolisable energy (ME) than Ross 208 requirements (Table 1).  
112Eight wheat samples originating from Germany and United Kingdom were obtained.  
113Dry matter (DM), gross energy (GE), fat, nitrogen (N), calcium (Ca) and the  
114phosphorous (P) contents of wheat samples were chemically analysed and further NIRS  
115analyses were performed (Tables 2 and 3). A fixed amount of each wheat (58.6%) was  
116used in the formula regardless of their chemical composition. Diets were predicted to

117contain 12.8 ME MJ/kg based on assumed average wheat apparent ME (AME) 58.6%  
118came from wheat grain. Control diets were supplemented with 16,000 BXU/kg of  
119xylanase following supplier recommendations (Econase XT, AB Vista, Marlborough,  
120UK; 160,000 BXU/g), resulting in 16 experimental diets in total. All diets contained  
121phytase supplemented at 500 FTU/kg (Quantum Blue, AB Vista, Marlborough, UK;  
1225000 FTU/g). Activity of xylanase and phytase were determined using the reference  
123method of analysis recommended by the supplier. Titanium dioxide (0.3%) was added  
124to all the diets as an indigestible marker. Feed samples were taken at the beginning and  
125throughout the experimental period for DM, N, fat and GE analysis.

126

#### 1272.3. Jejunal viscosity

128

129Approximately 1.5 g (wet weight) of the fresh jejunal digesta were analysed according  
130to Bedford et al. (1991). The viscosity (expressed as centipoise units,  $cP = 1/100$  dyne  
131 $\text{sec}/\text{cm}^2$ ) was determined using a Brookfield DV II digital viscometer.

132

#### 1332.4. Nutrient utilisation and total tract retention

134

135Total tract retention and ileal nutrient utilisation were calculated using the index method  
136(Olukosi et al., 2007), with titanium dioxide as the indigestible marker.

137

#### 1382.5. Net energy and nutrient accretion

139

140Net energy for production (NEp), heat production (HP) and carcass fat and protein  
141accretion 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 NE<sub>p</sub>, 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 NE<sub>p</sub> (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  
155Engineering Ltd., Birmingham, England, UK) at 105 °C 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).

167When effects were found to be significant, treatment means were separated using  
168Tukey's Highly Significant Difference test. Statistical significance was accepted at  $P <$   
1690.05 and trends were discussed at  $P < 0.10$ .

170

### 1713. Results

172

#### 1733.1. Wheat nutritive value by NIRS and chemical analyses

174

175The chemical analysis of the wheat samples indicates that they are all very similar in  
176chemical composition and GE (Table 2). The predicted nutritive values by NIRS  
177showed slightly more variability in nutrient composition between wheat varieties (Table  
1783), but remained close to expected average values. The predicted GE was  
179underestimated while the predicted fat content was higher than chemically analysed.  
180The predicted AME of wheat varieties ranged from 13.0 to 13.9 MJ/kg (CV < 2%).  
181There was a great deal of variability (CV > 10%) in the predicted contents for crude  
182protein, acid detergent fibre,  $\beta$ -glucan, lignin and total non-starch polysaccharides, but  
183low variability (CV < 8%) in all other analysed chemical components, including amino  
184acids.

185

#### 1863.2. Feed enzyme activity, growth performance and jejunal viscosity

187

188Enzyme activities in feed samples were close to expected (16,038 BXU/kg average  
189value analysed in all the xylanase-supplemented diets). No interactions were observed  
190in any of the performance parameters measured (Table 4). There were no effects of  
191wheat on performance or jejunal digesta viscosity. Nevertheless, improvements in

192performance were observed when xylanase was supplemented, regardless of wheat  
193sample. Xylanase application resulted in a near significant 20 g ( $P = 0.077$ ) increase in  
194BWG. Although FI was not influenced by xylanase, FCR was significantly improved by  
195four points better (1.33 vs. 1.37, xylanase vs. control, respectively;  $P = 0.003$ ). Xylanase  
196supplementation also reduced viscosity of jejunal digesta (3.32 vs. 2.34 cP, for control  
197and xylanase supplemented diets, respectively;  $P < 0.001$ ). In the diets without xylanase  
198supplementation, there were low and non-significant correlations between nutrient  
199content of the wheats and bird FCR (Table 5). For the birds receiving xylanase  
200supplemented diets, FCR was positively correlated with the analysed P and the  
201predicted contents by NIRS of NDF, total and soluble AX as well as insoluble NSP. In  
202addition, FCR was positively correlated with the analysed fat content.

203

### 2043.3. Nutrient utilisation and total tract retention

205

206No interactions between the main factors were observed for any of the ileal nutrient  
207utilisation results (Table 6). The DM utilisation of wheat 3 was significantly lower  
208compared with wheats 6, 7 and 8 ( $P < 0.05$ ), whereas wheats 1, 2, 4 and 5 had  
209intermediate values. Wheats 7 and 8 had greater energy utilisation ( $P < 0.001$ ) compared  
210with wheats 1, 2, 3 and 5, whereas wheats 4 and 6 were in between. Xylanase  
211supplementation increased ileal utilisation of energy (IDE) measured as MJ/kg ( $P =$   
2120.04), regardless of wheat. Ileal N utilisation tended to be influenced by wheat ( $P =$   
2130.06), and was not influenced by xylanase supplementation.

214There were significant interactions of the main factors for all total tract measurements  
215( $P < 0.001$ ). Xylanase supplementation improved the retention of DM and N as well as  
216AME and AMEn for diets based on wheats 2 and 6. For those diets based on wheats 3,

2174, 5 and 8 xylanase, inclusion led to no effect or marginally lower results in total tract  
218retention of N, AME and AMEn.

219

2203.4. Net energy and nutrient accretion

221

222There were no interactions between wheat and xylanase for any energy utilisation and  
223efficiency responses, except for HP and Kre-protein, and no xylanase effect on any of  
224the responses (Table 8). Net energy for production and  $K_{RE}$  were greater ( $P < 0.05$ ) for  
225wheat 2 compared with wheats 4, 5 and 7, but similar, although numerically higher, than  
226the other wheats. Energy retained as protein was greater ( $P < 0.05$ ) for wheats 3, 4 and 5  
227compared with wheats 7 and 8. Energy retained as fat and Kre-fat was greater ( $P < 0.05$ )  
228for wheat 2 than wheats 1, 3, 4 and 5. The interaction observed for HP ( $P = 0.02$ ) was  
229explained by xylanase supplementation increasing HP when birds were fed wheats 2  
230and 6 (data not shown), but decreased HP for wheat 8, with no effect observed for the  
231remaining wheats. The interaction noted for Kre-protein ( $P = 0.006$ ; data not shown)  
232was due to xylanase addition resulting in birds fed wheats 3 and 8 supplemented being  
233more efficient in protein accretion, whereas it was reduced for wheats 2 and 6, with no  
234effect on the remaining wheats.

235

2364. Discussion

237

238It is well known that wheats, even of the same variety, can vary in both chemical  
239composition and nutritive value (Theander et al., 1989). The current study investigated  
240the effect of wheat sample and xylanase supplementation on the performance of broilers  
241fed starter diets. In spite of the variability found between wheats in both the analysed

242chemical composition and that predicted by NIRS, performance was not affected.  
243Nevertheless, supplementation with xylanase improved BWG, FCR and reduced digesta  
244viscosity, as has been shown in numerous studies (Olukosi et al., 2007; Wu et al., 2004;  
245Zyla et al., 1999). **Arabinoxylan is the main NSP in cereals, representing about 60-70%**  
246**in the cell wall endosperm cells an aleurone layer. Although AX from different sources**  
247**differs in their substitution along the xylan backbone, a general structure can be**  
248**assigned for AX: a backbone of  $\beta$ -(1,4)-linked xylose residues, which are substituted**  
249**with arabinose residues on the C(O)-2 and/or C(O)-3 position and phenolic acids can be**  
250**linked on the C(O)-5 position of arabinose. The structure of AX leads to high water**  
251**holding capacity in the gastrointestinal tract resulting in high viscosity, and as a**  
252**consequence animal production process is less efficient. Xylanases cleave AX by**  
253**internally hydrolysing the  $\beta$ -1,4- $\beta$ -D-xylosidic linkage between xylose residues giving**  
254**small fragments of oligosaccharides with high or low degree of substitution (Mendis et**  
255**al. 2016). The successful exposure of xylanase to different wheats with variations in the**  
256**level content of soluble NSP makes them a feasible choice to mitigate the negative**  
257**effects of arabinoxylan (AX) in monogastrics (Bedford 2000).**

258

259Feed conversion ratio was not correlated with any of the analysed or predicted  
260composition values of wheat without xylanase, but those supplemented with the enzyme  
261had an unexpected positive correlation with the predicted contents of fat and fibre  
262components (NDF, AX, soluble AX and total insoluble NSP). These findings are  
263puzzling and suggest that the presence of more fibre (substrate) when the enzyme is  
264present resulted in poorer performance but that the presence of this fibre in the absence  
265of the enzyme was, if anything, marginally beneficial. Scott et al. (1999) found a

266significant relationship between predicted AME and FCR in wheat based diets with  
267enzymes ( $r = -0.46$ ), similarly found in this study ( $r = -0.45$ ).

268

269Non-starch polysaccharide degrading enzymes reduce digesta viscosity in the animal by  
270shortening the molecular weight of NSP and also partly remove the nutrient  
271encapsulation effect of the cell wall components and, as a consequence, nutrient  
272absorption is promoted and growth performance maximized (Masey O'Neill et al.,  
2732012, 2014a,b; Persia et al., 2002). In this study the measured intestinal viscosity of all  
274samples was extremely low in comparison with the literature, which suggests that the  
275wheat samples employed were not particularly challenging from a viscosity viewpoint.  
276In a similar study, xylanase supplementation improved performance in broilers fed  
277different Chinese maize samples varying in chemical composition, improving the  
278homogeneity in animal flocks with NSP-ases addition (Masey O'Neill et al., 2012).

279

280Some studies have reported improved performance and energy utilisation when NSP-  
281enzymes are used in diets based on wheat, rye, barley (Bedford and Morgan, 1996;  
282Bedford and Schulze, 1998) or maize (Masey O'Neill et al., 2012), but other studies  
283have only shown improvements in animal performance without changes in nutrient  
284utilisation (Hong et al., 2002; Wu et al., 2004). Wheat sample influenced ileal DM, N,  
285energy utilisation and IDE. In particular, wheats 6, 7 and 8 were particularly good  
286samples and this coincided with wheats 7 and 8 having the lowest viscosity. On the  
287other hand, wheats 6, 7 and 8 also had lower contents of N (and predicted crude  
288protein), acid detergent fiber, AX and NSP compared with the other wheats. Xylanase  
289use increased energy utilisation and AME. Aside from the effect of reducing viscosity,  
290there may be an additional benefit of increasing the permeability of the aleurone layer.

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

293

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

310

311 The response of broilers to dietary intervention in general and enzyme supplementation  
312 in particular is usually measured using growth performance responses or ileal nutrient  
313 utilisation and total tract nutrient retention. These can be adequate for measuring gross  
314 efficiency of nutrient utilisation, but to further characterize the efficiency of nutrient  
315 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  
324 $K_{RE}$  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



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

347

348 5. Conclusion

349

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

358

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360

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364

365 Conflict of interests

366

367 All authors declare no conflict of interests.

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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 <sup>1</sup>	4.90	4.90
Phytase <sup>2</sup>	+	+
Xylanase <sup>3</sup>	-	+
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<sup>1</sup> Vitamin/mineral premix supply per kilogram of diet: vitamin A, 16,000 IU; vitamin

467D<sub>3</sub>, 3000 IU; vitamin E, 25 IU; vitamin B<sub>1</sub>, 3 mg; vitamin B<sub>2</sub>, 10 mg; vitamin B<sub>6</sub>, 3 mg;

468vitamin B<sub>12</sub>, 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<sup>2</sup> Quantum Blue 5G, AB Vista, Marlborough, UK; 5000 FTU/g.

474<sup>3</sup> 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								CV
	1	2	3	4	5	6	7	8	
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								CV
	1	2	3	4	5	6	7	8	
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
$\beta$ -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

481GE= gross energy; AME = apparent metabolisable energy; NDF = neutral detergent

482fibre; ADF = acid detergent fibre; AX = arabinoxylan; NSP = non-starch

483polysaccharides; CP = crude protein.

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507 Table 4 Animal performance and jejunal digesta viscosity<sup>1</sup>

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 <sup>b</sup>	1088	1.373 <sup>a</sup>	3.32 <sup>a</sup>
16,000 BXU/kg	813 <sup>a</sup>	1079	1.331 <sup>b</sup>	2.34 <sup>b</sup>
SEM	8	8	0.010	0.03
<i>P</i> -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<sup>a,b</sup> Means in the same column with different letters differ at  $P < 0.05$ .

509<sup>1</sup> Mean values for six replicate cages with eight broilers per replicate cage.

510 Table 5 Correlation of feed conversion ratio (FCR) with the analysed chemical  
 511 composition and the predicted values by near-infrared spectroscopy (NIRS) of wheat in  
 512 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

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

516 \* $P < 0.05$

517Table 6 Ileal nutrient utilisation of nutrients<sup>1</sup>

Item	Dry matter, %	Nitrogen, %	Energy, %	IDE, MJ/kg
Wheat effect				
1	68.0 <sup>bc</sup>	78.0	70.8 <sup>bc</sup>	13.2 <sup>b</sup>
2	66.9 <sup>bc</sup>	74.8	70.0 <sup>c</sup>	13.1 <sup>b</sup>
3	65.2 <sup>c</sup>	74.4	69.5 <sup>c</sup>	13.2 <sup>b</sup>
4	68.8 <sup>bc</sup>	78.2	72.0 <sup>abc</sup>	13.7 <sup>ab</sup>
5	66.9 <sup>bc</sup>	75.9	69.6 <sup>c</sup>	13.0 <sup>b</sup>
6	70.2 <sup>ab</sup>	78.1	73.2 <sup>abc</sup>	13.8 <sup>ab</sup>
7	70.4 <sup>ab</sup>	79.4	73.9 <sup>ab</sup>	14.0 <sup>a</sup>
8	73.0 <sup>a</sup>	79.7	76.0 <sup>a</sup>	14.4 <sup>a</sup>
SEM	1.47	1.42	1.47	0.28
Xylanase effect				
0 BXU/kg	67.8	76.9	70.9 <sup>b</sup>	13.35 <sup>b</sup>
16,000 BXU/kg	69.5	77.8	72.9 <sup>a</sup>	13.77 <sup>a</sup>
SEM	0.74	0.71	0.74	0.14
<i>P</i> -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<sup>a-c</sup> Means in the same column with different letters differ at  $P < 0.05$ .

520<sup>1</sup>Mean values for six replicate cages with eight broilers per replicate cage.

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524 Table 7 Total tract retention of nutrients<sup>1</sup>

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

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

526<sup>a-e</sup> Different letters mean significant differences between treatments, highlighting the

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

528<sup>1</sup> 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<sup>1</sup>

Item	Energy utilisation, MJ/kg		Energy retained, MJ/kg		Efficiencies of energy use for energy, protein and fat retention accretion		
	Nep <sup>2</sup>	HP <sup>3</sup>	Protein-ER <sup>4</sup>	Fat-ER <sup>5</sup>	K <sub>RE</sub> <sup>6</sup>	Kre-Protein <sup>7</sup>	Kre-Fat <sup>8</sup>
<b>Wheat effect</b>							
1	5.59 <sup>abc</sup>	6.84 <sup>bc</sup>	3.92 <sup>ab</sup>	2.20 <sup>bc</sup>	0.45 <sup>bc</sup>	0.275 <sup>ab</sup>	0.154 <sup>abcd</sup>
2	5.94 <sup>a</sup>	6.35 <sup>d</sup>	3.89 <sup>ab</sup>	2.48 <sup>a</sup>	0.48 <sup>a</sup>	0.275 <sup>ab</sup>	0.175 <sup>a</sup>
3	5.53 <sup>abc</sup>	6.54 <sup>cd</sup>	3.94 <sup>a</sup>	2.04 <sup>c</sup>	0.46 <sup>ab</sup>	0.289 <sup>a</sup>	0.149 <sup>bcd</sup>
4	5.53 <sup>c</sup>	7.24 <sup>a</sup>	3.95 <sup>a</sup>	2.04 <sup>c</sup>	0.43 <sup>c</sup>	0.269 <sup>bc</sup>	0.139 <sup>d</sup>
5	5.32 <sup>c</sup>	6.74 <sup>bc</sup>	3.96 <sup>a</sup>	2.05 <sup>c</sup>	0.44 <sup>bc</sup>	0.277 <sup>ab</sup>	0.143 <sup>cd</sup>
6	5.64 <sup>abc</sup>	6.60 <sup>bcd</sup>	3.89 <sup>ab</sup>	2.24 <sup>abc</sup>	0.46 <sup>ab</sup>	0.275 <sup>ab</sup>	0.158 <sup>abcd</sup>
7	5.72 <sup>bc</sup>	6.44 <sup>bcd</sup>	3.83 <sup>b</sup>	2.25 <sup>abc</sup>	0.47 <sup>b</sup>	0.278 <sup>ab</sup>	0.163 <sup>ab</sup>
8	5.77 <sup>ab</sup>	7.22 <sup>ab</sup>	3.84 <sup>b</sup>	2.41 <sup>ab</sup>	0.44 <sup>bc</sup>	0.258 <sup>c</sup>	0.162 <sup>abc</sup>
SEM	0.135	0.155	0.031	0.098	0.011	0.0050	0.0078
<b>Xylanase effect</b>							
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
<b>P-value</b>							
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
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535<sup>1</sup>Mean values for six replicate cages with one broiler per replicate cage.

536<sup>2</sup> NEp - net energy for production.

537<sup>3</sup> HP - heat production.

538<sup>4</sup> Protein-ER - energy retained as protein.

539<sup>5</sup> Fat ER - energy retained as fat.

540<sup>6</sup> K<sub>RE</sub> - efficiency of energy use for production.

541<sup>7</sup> Kre-Protein - efficiency of energy use for protein accretion.

542<sup>8</sup> Kre-Fat - efficiency of energy use for fat accretion.

543<sup>a-d</sup> Means in the same column with different letters differ at  $P < 0.05$ .