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Wheat sample affects growth performance and the apparent metabolisable energy value for broiler chickens

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ABSTRACT

1. The aim of this study was to examine chemical composition, quality characteristics, apparent metabolisable energy (AME) and nutrient utilisation of wheat samples currently available to the UK poultry industry and their effect on broiler growth performance.

2. Seventeen current UK wheat samples were used to formulate 17 diets, all of which included 670 g/kg of each wheat sample and 330 g/kg of a balancer feed. Eight hundred (800), day old male Ross 308 broilers were allocated randomly to 160 raised floor pens. Each diet was replicated eight times, fed *ad libitum* from 0 to 21d age in a randomised complete block design. Excreta were quantitatively collected during the last three days for AME determination.

3. The content of protein, ash and gross energy (GE) ranged from 97 to 143 g/kg DM, 12.8 to 19.6 g/kg DM and 17.81 to 18.24 MJ/kg DM, respectively. The amount of starch and total non-starch polysaccharides (NSP) ranged from 671 to 728 and 80.1 to 98.2 g/kg DM, respectively. The quality characteristics of wheat samples were in the expected range.

4. There were differences ($P < 0.05$) in AME and AMEn of wheat samples. The AME of the wheat had a maximum range of 1.13 MJ/kg DM between samples. Dry matter retention (DMR) and fat digestibility (FD) were significantly different ($P < 0.05$) between wheat samples.

5. The daily feed intake (FI) and weight gain (WG) of broilers fed two wheat samples were significantly ($P < 0.05$) lower as compared to other samples and

their low FI and WG were not related to their chemical composition and quality characteristics.

6. The ash content of wheat samples was negatively associated with AMEn (r = − 0.489, $P < 0.05$). The coefficient of FD was positively related to AMEn (r = 0.552, $P < 0.05$).
7. Chemical composition and quality characteristics of the wheat did not relate ($P > 0.05$) to FI and WG of broilers. There was also no relationship between growth performance of broilers and AMEn of the wheat samples.

KEYWORDS: wheat, chickens, metabolisable energy, feed intake, weight gain

Introduction

The main goal of efficient broiler production is to achieve good growth performance with high feed efficiency. Wheat, specifically grown for feed and also that in excess of milling processes (bread, biscuits, cakes), is the main cereal used in commercial broiler diet formulations in the UK and northern Europe. High yield and low cost available energy (price/MJ of metabolisable energy) make wheat one of the most economically competitive cereals in poultry feed, accounting for up to 70 % of the metabolisable energy (ME) and 35 % of the protein requirements of commercial broilers (Gutierrez del Alamo et al. 2008b). There is, however, considerable variation in ME content of wheat samples, with ranges between 8.5 – 16.4 MJ/kg DM (McNab 1991; Wiseman 2000; Ravindran and Amerah 2009). This large variation in ME content of wheat makes it challenging for nutritionists to predict the feeding value of wheat for broilers.

The majority of the work on UK wheat samples and their effect on apparent metabolisable energy (AME) and broiler growth performance was conducted 15 – 20 years ago (Waldron 1997; McCracken and Quintin 2000; Wiseman 2000; Rose et al. 2001; Pirgozliev et al. 2003). These studies have not demonstrated conclusive information on how chemical composition and quality characteristics of wheat are related to AME and growth performance of broilers, however, they have indicated that differences in AME exist (Waldron 1997; Scott et al. 1998; Steenfeldt 2001). Starch is the main energy yielding component of wheat, but inconsistent relationship between starch and AME of wheat was reported (Svihus and Gullord 2002; McCracken et al. 2002). Instead of starch contents, digestibility of starch in wheat based diets was associated with AME (Wiseman et al. 2000; Carre et al. 2005).

Broiler response to wheat based diets in many previous studies have been due to differences in protein contents of wheat samples (Steenfeldt 2001; Pirgozliev et al. 2003; Hetland et al. 2004). The protein content of the wheat is variable, ranges between 8 – 17 % depending on variety and the growing condition (Scott et al. 1998; Wiseman 2000; McCracken et al. 2002). Protein content of wheat is inversely related to starch content (Svihus and Gullord 2002; Ravindran and Amerah 2009). Therefore, there is a need to consider the factors other than protein such as starch, non-starch polysaccharides (NSP) and investigate their relationship with broiler growth performance and ME. Current wheat cultivars have undergone numerous changes in chemical composition, quality and yield. High yield wheat varieties with better resistance to diseases have been produced (AHDB 2015). Wheat genotype, soil composition, seasonal changes, crop husbandry and agronomic factors have changed UK wheat significantly in the last two decades. Wheat varieties with low arabinoxylans are now available, which have the benefit of conferring a low ileal digesta viscosity for broilers resulting in improvement in growth performance of broilers (Choct and Annison 1992a, b; Pirgozliev et al. 2015).

The objectives of this study were (a) to define the chemical composition, quality characteristics of current UK grown wheat samples, (b) to investigate the differences in AME and growth performance of broilers (c) to determine if differences were related to chemical composition, quality characteristics and nutrient utilisation of the wheat.

Materials and methods

Wheat samples

Seventeen UK wheat samples harvested in the year 2015, sourced from Klien Wanzlebener Saatzucht (KWS UK Ltd), grown on four different sites in the UK (Yorkshire, Nottinghamshire, Lincolnshire and Cambridge) were used in this study (Table 1). The samples were specifically grown for this study and were among currently available UK wheat samples (AHDB recommended list 2016/2017). Wheat samples comprised of hard feed wheat, soft feed wheat, hard milling wheat and soft milling wheat. Hard milling varieties (Lili and Trinity) are used for bread making markets, while soft varieties (Barrel and Basset) are suitable for cakes and biscuits. Feed wheat varieties are high yield varieties, specifically grown for animal feed industry. Wheat samples were received in 25 kg bags. Each sample was mixed homogenously from 10 minutes, and random samples were collected for analyses. The collected samples were milled to pass through a 0.75 mm screen using Retsch ZM 200 (Retsch GmbH, Haan, Germany). All analyses were performed in duplicates.

Proximate analysis of samples

Dry matter (DM) was determined by drying samples in a forced draft oven at 105 ˚C to a constant weight (AOAC, 2012; 934.01). Crude protein (CP) (6.25 × N) was determined by dry combustion method (AOAC, 2012; 990.03) using a LECO FP-528 N (Leco Corp., St. Joseph, MI, USA). Fat (as ether extract) was extracted with 40 – 60 ^{0}C petroleum ether by ether extraction method (AOAC, 2012; 920.39) using a Soxtec system (Foss UK Ltd, Warrington, UK). Gross energy (GE) was determined in a bomb calorimeter (model 6200; Parr Instrument Co., Moline, IL, USA). Crude ash was determined in a muffle furnace at 550 °C for 4 h (AOAC, 2012; 942.05).

Carbohydrate analysis

Total starch (TS) was analysed following the method of Englyst et al. (2000). Wheat non-starch polysaccharide fraction (NSP) was determined by the method of Englyst et al. (1994), by starch dispersion and then hydrolysed enzymatically. The NSP is isolated by precipitation in 80 % ethanol, then hydrolysed by sulphuric acid and the released sugars were measured by gas chromatography as their alditol acetate derivatives.

Grain quality analysis

Hagberg falling number (HFN) was determined by HFN apparatus model 1400 (Falling Number AB, Stockholm, Sweden) (AOAC 976.13). Specific weight (SW) kg/hectolitre (hl) was determined by Chondrometer (Farm Tec, Yorkshire, UK). Endosperm Hardness (EH) was determined using a Single Kernel Characterisation System (SKCS 4100, Perton Instrument, Hagersten, Sweden). Three hundred (300) kernels of cleaned wheat were assessed for each sample. Thousand grain weights (TGW) of wheat samples was determined by weighing 1000 randomly selected grains. Dynamic water extract viscosity (DV) was determined by cup and cone viscometer (model DV-II + LV, Brookfield, Stoughton, MA, USA) as described by Pirgozliev et al. (2003). The Wheat sample (2 g) was soaked in distilled water (4 ml) in a glass tube in water bath at 40°C for 30 minutes. Then each tube was centrifuged at 10000 x g for 2 minutes. The tubes were left for 15 minutes at room temperature and 0.5 ml aliquot in duplicates was taken for viscosity measurement. The viscosity of supernatant was measured in centipoise (cP) by viscometer. Kinematic water extracted viscosity (KV) of wheat samples was determined using an automated viscometer (AVS 370 SCHOTT Instruments, Analytics, Germany) fitted with an Ostwald capillary tube (Saulnier et al., 1995).

Diet preparation

Each wheat sample was milled to pass through a 3 mm screen and mixed with a balancer feed (Target Feeds Ltd, Whitchurch, UK). A balancer feed was formulated including major ingredients of 521.3 g/kg soybean meal (SBM), 299.2 g/kg of full-fat soymeal, 60.5 g/kg soya oil, and contained 374.5 g/kg CP and 12.45 MJ/kg AME (Table 2). Hammer mill was cleaned after milling each wheat sample to avoid any cross contamination of different samples. Seventeen diets were prepared by mixing 645 g/kg of each of the seventeen experimental wheat samples with 330 g/kg of a balancer feed. Diets were made iso-nitrogenous by adding wheat protein isolate (WPI) (25 g/kg) to each wheat sample by substituting wheat with WPI. The additional quantity of WPI to be added was estimated on analysed protein value of each wheat sample on *as fed basis.* A relatively small contribution of energy provided by additional protein was taken into consideration during AME determination of each diet. The determined AME of the diet in this study was the AME of the mixture (wheat plus WPI).

The AME was not determined on balancer diet because it would have inappropriate supply of nutrients for broilers. Three additional diets (18, 19, 20) were formulated by mixing 470, 570 and 770 g/kg of one of the wheats (sample 8) with 530, 430 and 230 g/kg of balancer feed, respectively for AME determination of balancer diet by slope ratio method (Finney 1978). The nutritional profile of each additional diet was closed to nutrient specification of broilers. AME of balancer diet was then predicted by regression analysis of diet 8, 18, 19 and 20. Sample 8 was chosen at random to formulate additional three diets. The diets were pelleted at NIPH (The National Institute of Poultry Husbandry) Harper Adams University using a laboratory pelleter (KAHL, Amandus Kahl GmbH & Co. KG, Reinbek, Germany). The frequency of pelleter was 50Hz and temperature of the jacket ranged between 44.5°C – 46.5°C. Pellets were produced at temperature ranged between 59°C – 62.5°C. No steam was used during pelleting. The whole pelleting process was in a controlled environment, strictly monitoring speed of the feeder, frequency of pelleter, and temperature of pellets produced. Pellets were cool down to ambient temperature by ventilated cool air for 30 mins and then stored in bags. Pellets were stored at temperature below 18°C. The diameter and length of pellet was 3 mm and 4 – 7 mm, respectively. Each experimental diet met or exceeded the diet specification for Ross male 308 broiler chickens (Aviagen Ltd. Edinburgh, UK). Diets were free of coccidiostats, antimicrobial growth promoters or other similar additives. Pellet durability index (PDI**)** was also determined in duplicates to test the pellet quality using a Holmen Pellet Tester (NHP100 Portable Pellet Durability Tester, TekPro Ltd, Norfolk, UK). The values of PDI ranged from 80.2 to 83.8 %.

Husbandry and sample collection

All procedures were approved by Harper Adams University Research Ethics Committee. Eight hundred (800), one day old male Ross 308 broilers were obtained from a commercial hatchery, weighed individually and allocated randomly to 160 raised floor pens with 0.360 m^2 solid floors area, five birds in each pen. Each diet was randomly assigned to eight pens within blocks (positioned within the house) and fed from 0 – 21 days. Feed and water were offered *ad libitum* to birds throughout the experiment. Each pen was equipped with a feeding trough outside the pen and automatic drinkers inside the pen. The temperature was maintained at 32°C for first day of the study and was reduced gradually to 21°C at the end of study (d 21). A standard lighting programme was followed decreasing the light: dark ratio from 23 h: 1 h from day old to 18 h: 6 h at d 7, which was maintained till d 21 (Aviagen Ltd. Edinburgh, UK). Birds were fed experimental wheat based mash diets during the first seven days and pellet diets from 7 to 21 d of age. Body weights were recorded at the beginning and at the end of experiment (d 21). The birds were inspected daily, and dead birds were weighed at the time of removal. Feed intake per pen (FI) was recorded and feed conversion ratio (FCR) was calculated on a pen weight basis. The body weights of dead birds were included to calculate FCR.

Excreta collection

At d 18, the solid floor of each pen was replaced with a wire mesh and plastic trays were placed underneath for excreta collection. Excreta were quantitatively collected every 12 hours from each pen for three consecutive days (19 – 21 days) and immediately dried at 60 °C in a forced draft oven, weighed and milled by Retsch ZM 200 (Retsch GmbH, Haan, Germany) using a 0.75 mm screen. Feathers and scales were removed carefully to avoid any contamination. The feed intake was recorded for the same period. The dry matter (DM) content, gross energy (GE), nitrogen and fat (as ether extract) of excreta and the experimental diets were determined as described for the wheat samples. All analyses were performed in duplicates. The AME values of the diets on a dry matter basis were determined by equation (1).

$$\text{AME}_{\text{diet}}\ (\text{MJ/kg DM}) = \frac{(\text{Feed intake x GE}_{\text{diet}}) - (\text{Excreta output x GE}_{\text{excreta}})}{\text{Feed intake}} \quad (1)$$

$$\text{AMEn}_{\text{diet}}\ (\text{MJ/kg DM}) = \frac{((\text{Feed intake x GE}_{\text{diet}}) - (\text{Excreta output x GE}_{\text{excreta}})) - (\text{N}_{\text{retained}} \text{ x } 34.39)}{\text{Feed intake}} \quad (2)$$

$$\text{Nutrient retention coefficient} = \frac{(\text{Feed intake x Nutrient}_{\text{diet}}) - (\text{Excreta output x Nutrient}_{\text{excreta}})}{\text{Feed intake x Nutrient}_{\text{diet}}} \quad (3)$$

$$\text{AME}_{\text{wheat}}\ (\text{MJ/kg DM}) = \frac{\text{AME}_{\text{diet}} - (\text{AME}_{\text{balancer diet}} \text{ x } 0.33)}{0.67} \quad (4)$$

Nitrogen corrected AME (AMEn) was determined by correction for zero N retention by multiplication with 34.39 MJ/kg N retained in the body (2) as described by Hill and Anderson (1958). The coefficients of nitrogen retention (NR), fat digestibility (FD) and dry matter retention (DMR) were determined as the difference between nutrient intake and excretion of each nutrient divided by nutrient intake (3).

The AME of wheat and coefficients of nutrient retention were calculated by substitution method using equation (4). Linear regression analysis was used to test the linear response of bioavailable energy and nutrient retention at four inclusion levels of wheat (470, 570, 670, 770). There was a linear response ($P < 0.05$) to inclusion levels of wheat for AME and AMEn and determined nutrients with no evidence of non-linearity ($P > 0.05$). The AME and nutrient retention constant of balancer diet was determined by linear regression analysis of diets 8, 18, 19, 20 and used in equation 4 to predict the AME and total tract nutrient retention of wheat.

At the end of trial, at 21 d of age, all five birds in each pen were weighed and killed by cervical dislocation. The contents of ileal digesta from Meckel's diverticulum to ileal-caecal junction were gently pressed from each bird and pooled by pen, homogenised, then centrifuged (10,000 x g for 2 min). The viscosity of the supernatant was measured using a rotating cone and cup viscometer (model DV – II + LV, Brookfield Stoughton, MA, USA) as described by Bedford and Classen (1992).

Statistical analysis

Statistical analyses were performed in GenStat statistical software (GenStat 17th edition supplied by VSN international Ltd, UK). Broiler growth performance, AME, AMEn values of wheat samples and nutrient retention coefficients were subjected to analysis of variance (ANOVA) in a randomised block design, with a single pen representing experimental unit (replicate). Treatments and block were fixed effects. The variables that described growth performance were feed intake gram per bird per day (FI), weight gain gram per bird per day (WG), final body weight kilogram per bird (BW), feed conversion ratio (FCR) corrected for mortality (g of feed intake per g of weight gain). Means were separated using Duncan multiple range test and differences were significant at $P < 0.05$. Least significant difference (LSD) test was used for illustration purpose to report the significant differences.

Correlation coefficients were also generated to test for any linear relationships between chemical composition and grain quality measurements of wheat samples with AME, nutrient utilisation and growth performance of broilers. Relationships were reported at significance level ($P < 0.05$; r = 0.482, $P < 0.01$; r = 0.606 and $P < 0.1$; r = 0.412). Simple and stepwise multiple linear regression analysis was used to assess the relationship between broiler growth performance, determined AME and characteristics of wheat samples (chemical composition and grain quality). A stepwise regression technique was used to evaluate the effects of the independent variables into a linear model. Chemical composition and grain quality measurements of wheat samples were used as independent variables in stepwise regression. The variables FI, WG, FCR and determined AME of wheat samples were used separately as dependent variables. The independent variables were added one at a time in the model starting with highest correlation with dependant variables. Contribution of each variable was analysed statistically before entering next variable. If a nonsignificant variance was found, it was removed from the model. Variables were added to independent variables until there was no further improvement in variance and addition of variables were statistical significance ($P < 0.05$) in the equation.

Results

Chemical composition

The chemical composition of seventeen wheat samples is summarised in Table 3. The dry matter (DM) content varied in the range of 873 to 910 g/kg. The amount of protein and fat (as ether extract) in wheat samples ranged from 97 to 143 g/kg DM and 10.9 to 17.4 g/kg DM, respectively. The ash content between samples ranged from 12.8 to 19.6 g/kg DM. Gross energy (GE) was less variable between samples and ranged from 17.81 to 18.24 MJ/kg DM. The amount of starch in the wheat samples varied from 671 to 728 g/kg DM. The non-starch polysaccharides (NSP) content ranged from 80.1 to 98.2 g/kg DM. Soluble and insoluble NSP in wheat samples ranged from 11.2 to 23.2 g/kg DM and 63.7 to 80.2 g/kg DM, respectively.

Grain quality

The values of Hagberg falling numbers (HFN) between seventeen wheat samples ranged from 130 to 384 (Table 4). Endosperm hardness (EH) of wheat samples ranged from 21 to 87 relative units (soft to hard). The values of HFN and EH were variable between samples because of different wheat types (feed wheat, milling). The specific weight (SW) of wheat samples ranged from 75.4 to 82.4 kg/hl. The thousand grain weights (TGW) ranged between 45.7 to 59.9 g. The dynamic water extract viscosity (DV) ranged between 2.4 to 6 cP (centipoise), whereas kinematic water extract viscosity (KV) ranged between 1.17 to 1.56 cSt (centistokes). Dry matter (DM) of all experimental diets ranged from 890 to 916 g/kg DM.

Apparent metabolisable energy and nutrient utilisation

The determined AME of seventeen individual wheat samples ranged from 13.68 to 14.81 MJ/kg DM ($CV^{m\ (of\ 17\ individual\ samples)}$ = 4.2 %). The determined AMEn of wheat samples ranged from 13.32 to 14.36 MJ/kg DM (CV^{m} = 4.1 %), respectively (Table 5). There were differences ($P < 0.05$) in AME and AMEn between individual wheat samples. There were also differences ($P < 0.05$) in GE metabolisability of wheat samples and AME: GE ratio ranged from 0.762 to 0.822 (CV^{m} = 4.2 %), similarly AMEn: GE ratio ranged from 0.742 to 0.797 (CV^{m} = 4.1 %).

There were no differences ($P > 0.05$) in the coefficient of total tract nitrogen retention (NR) between the seventeen wheat samples. Differences were observed for coefficients of fat digestibility (FD) and dry matter retention (DMR) ($P < 0.05$, $P < 0.001$, respectively) (Table 6). Nitrogen retention (NR) ranged from 0.545 to 0.607(CV^{m} = 8.2 %), FD ranged from 0.605 to 0.742 (CV^{m} = 11.6 %) and DMR ranged from 0.763 to 0.811, (CV^{m} = 3.6 %).

Broiler growth performance

There were differences ($P < 0.05$) in FI (CV ^{m} = 8.5 %), WG (CV ^{m} = 7.9 %) and BW (CV ^{m} = 7.5 %) of broilers fed seventeen wheat based diets (Table 6). Although, there were differences in FI and WG of broilers but no differences ($P > 0.05$) in FCR were observed between wheat samples and values of FCR ranged from 1.197 to 1.243 (CV ^{m} = 3.2 %). There were no differences ($P > 0.05$, CV ^{m} = 26.3 %) in ileal digesta viscosity of broilers.

Relationship between characteristics of the wheat and AME and growth performance

A correlation matrix was initially used to compare the relationships between wheat samples laboratory analyses and AME and broiler growth performance (Table 7). Ash was negatively correlated with AME and AMEn (r = 0.513, 0.489; $P < 0.05$, respectively). There was a tendency of a negative relationship between insoluble NSP and AME, AMEn (r = 0.466, 0.464; $P < 0.1$). There were positive relationships between the coefficients of NR, FD and AMEn (r = 0.496, 0.552; $P < 0.05$, respectively). Dry matter retention (DMR) was positively correlated with AMEn (r = 0.726; $P < 0.001$). Broiler growth performance did not correlate ($P > 0.05$) with AME and AMEn of the wheat samples.

Although, there were differences in FI and WG of broilers when they were fed different wheat samples, there was no relationship ($P > 0.05$) between growth performance and wheat chemical composition. Specific weight (SW) was the only characteristics of wheat samples which was positively correlated (r = 0.515; $P < 0.05$) with FCR. Feed intake of broilers was correlated (r = 0.953; $P < 0.001$) with WG of broilers.

Stepwise multiple linear regression analysis indicated that wheat variables ash, soluble NSP and CP in combination gave the best explanation ($r^2 = 0.59$; $P < 0.05$) of variation in AME of wheat but only accounted for 59 % variability in AME. The addition of any further explanatory variables did not significantly ($P > 0.05$) reduce residual mean squares in AME. The determined AME and wheat characteristics variables were also tested for non-linear regression, however there was no evidence of non-linear (P > 0.05) response between AME and wheat variables. There was no relationship ($P > 0.05$) between the combination of wheat chemical composition, quality characteristics and growth performance of chickens.

Discussion

The study evaluated the effect of wheat samples that represented the range and quality of samples currently available to the UK poultry industry, with different chemical composition and quality characteristics, on metabolisable energy, nutrient utilisation of wheat and growth performance of broilers. The findings of this study are important for nutritionists because a large set of currently available UK wheat samples for poultry feeds were investigated and variability between different samples were studied.

Chemical composition

The proximate nutrient composition and GE contents were in a similar range to earlier studies (Preston et al. 2000; Rose et al. 2001; Amerah et al. 2008; Pirgozliev et al. 2015). The contents of CP were variable (CV = 8.3 %) between wheat samples, in agreement with Hetland et al. (2007) and Gutierrez del Alamo et al. (2008a). The amounts of total starch and NSP were in a similar range as reported by previous findings (Annison 1990; Waldron 1997; McCracken and Quintin 2000; Carre et al.

2005). Chemical composition of wheat varies due to numerous factors including growing season, soil type, location, crop husbandry and genetic origin of the wheat (Gutierrez del Alamo et al. 2008b, Ravindran and Amerah, 2009).

Quality characteristics

The values of HFN in wheat samples were in the similar range to earlier reported results (Rose et al. 2001; Hetland et al. 2007), though their reported HFN were generally higher than the values in present study, possibly due to differences in growing condition, effect of weather and storage. Hagberg falling number was variable between seventeen samples (CV= 28.7 %), and soft and hard milling wheats had relatively high HFN as compared to feed wheat. High α-amylase activity was recorded in feed wheats (Leeds and Santiago) with a lower HFN. The relative units of EH were in agreement of previous studies (Rose et al. 2001; Pirgozliev et al. 2003; Amerah et al., 2008). Wheat endosperm hardness is an important characteristic in the quality of wheat for bread making, cakes or biscuits. Hardness of wheat affects the milling performance of the wheat. Hard wheat shatters when milled and the flour is fine, with regular particle size and large surface area (Rose et al. 2001; Ball et al. 2013). The specific weight of wheat samples were less variable between samples (CV= 2.8 %) and agreed with previous findings (Wiseman 2000; McCracken et al. 2002; Gutierrez del Alamo et al. 2008a).

Energy availability, nutrient utilisation

The differences in AME values of experimental wheat samples were in the expected range and in agreement with previous findings (McCracken and Quintin 2000; Steenfeldt 2001; Pirgozliev et al. 2003; Smeets et al. 2015). The values of AME between individual wheat samples were significantly different ($P < 0.05$; LSD = 0.60 MJ/kg DM), similarly AMEn values of individual wheat samples were also significantly different ($P < 0.05$; LSD = 0.57 MJ/kg DM). Some of the previous studies reported no difference in AME between wheat samples (Wiseman 2000; Amerah et al. 2008), but only physical characteristics were measured in the former study, while only two samples were analysed in the latter. In this study, maximum range of differences in AME and AMEn between samples were 1.13 and 1.04 MJ/kg DM, respectively. The AME value of sample 15 was 8.3 % higher than lowest AME value sample 8. The N corrected AME (AMEn) of sample 15 was 7.8 % higher than the lowest AMEn value sample 8. The difference of 1 MJ/kg between samples is commercially important in broiler feed formulation and indicates that there is important variation between AME of different currently available UK wheat samples. The coefficients of NR, FD and DMR results were in expected range and in accord with previous reports (Steenfeldt 2001; Pirgozliev et al. 2015; Smeets et al. 2015). The values of DMR of sample 15 were 6.15 % higher than sample 8 which correspond to difference in AME between these two samples. There was a difference of 21.5 % in FD between average lowest and highest values of wheat.

Relationship between chemical composition, quality characteristics, nutrient utilisation and apparent metabolisable energy of wheat samples

There was no significant association of major energy yielding components of wheat including starch and protein with AME. The only significant ($P < 0.05$) relationship was, a negative association of ash with AME ($r^2 = 0.21$; $P < 0.05$). Simple linear regression analysis indicated that only 21% of the variation in AME was explained by the ash contents of wheat samples. The results of stepwise multiple linear regression analysis indicated that only 59 % variability in AME of studied wheat samples was explained ($P < 0.05$) when ash, soluble NSP and CP were used in combination. The addition of any other chemical composition variables of wheat did not further explain variability in AME. Researchers have found negative correlation between CP and AME (Svihus and Gullord 2002; Ball et al. 2013) but this study indicated only a tendency for a negative correlation between CP of wheat samples with AME and AMEn. The tendency of a negative association between insoluble NSP and AME was in accord with previous published data (Annison 1991, 1993; Smeets et al. 2015). Studies had indicated that variation in NSP content of wheat could affect ME and broilers growth performance (Choct et al. 1995; Hetland et al. 2004). Non-starch polysaccharides are encapsulated within the cell wall, making it difficult for endogenous enzyme to release them. Most of the arabinoxylans in wheat are insoluble and inaccessible to birds as nutrients (Bedford and Morgan 1996; Choct 2006). In this study, there were variations (CV = 23.1 %) in soluble NSP content of wheat samples; however, there was no significant association of soluble NSP with AME, which were in agreement of previous findings (Steenfeldt 2001; Choct et al. 2006). The tendency of relationship between soluble NSP and ileal digesta viscosity ($r = 0.444$, $P < 0.1$) suggests that soluble NSP are not always associated with a reduction in ME by increasing ileal digesta viscosity. The lack of relationship between starch and AME was not surprising and has been reported previously (McCracken et al. 2002; Gutierrez del Alamo et al. 2008a). Starch and protein are encapsulated by the cell wall in wheat endosperm cells. Steam conditioning during pelleting can damage cell walls to release starch, resulting in improved ME. In the present study, diets were pelleted without steam, and absence of steam conditioning may not release starch completely. The absence of relationship of starch with AME could also be due to less variability (CV = 2.2 %) in starch contents of studied wheat samples.

The lack of correlation between SW and AME confirmed previous reports (Wiseman 2000; Svihus and Gullord 2002) and could be due to less variation in SW (CV = 2.8

%) between wheat samples. Specific weight is most commonly used by feed millers to accept wheat samples based on their yield (kg/hl). High yield varieties do not always correspond to high AME. In this study, the quality characteristics of wheat samples did not relate to AME, which indicated that quality characteristics cannot be relied upon to determine the feeding value of wheat. Researchers so far have been unable to establish a consistent relationship between wheat quality characteristics and AME (McCracken et al. 2002; Hetland et al. 2007; Ball et al. 2013). A significant positive correlation between FD and AMEn confirmed previous results of Steenfeldt (2001) and could be due to high variability (CV = 11.6 %) in FD. In this study, the positive relationship between FD and AMEn indicated that although starch is the main energy yielding component in wheat, high FD may also contribute towards higher AMEn of wheat to some extent, though this contribution is not significant enough to be accounted for major variation in AMEn. The positive correlation between nutrient digestibility and AMEn indicates that AMEn is only improved if diets have highly digestible nutrients and alongside starch, other nutrients contribute towards available energy from wheat.

Relationship between chemical composition, quality characteristics of wheat samples and growth performance of broilers

The current study revealed that there were large differences (13 – 14 %) in FI and growth rate of broilers, which cannot be fully explained by the wheat chemical composition. The tendency of relationship between ash content of wheat samples and WG was in agreement with the previous work of Pirgozliev et al. (2003). The variations in ash content of wheat samples could be due to soil contamination.

The current study reported no relationship between EH of wheat samples and growth performance. The published literature on the effect of EH on growth performance is inconsistent. Rose et al. (2001) reported a positive correlation between endosperm hardness and feed intake and weight gain. Amerah et al. (2008) found increase in feed intake of broilers fed soft wheat-based diets supplemented with enzyme, but no improvement in hard wheat. Salah Uddin et al. (1996) reported no effect of endosperm hardness on broiler performance in pellet diet. Pirgozliev et al. (2016) compared pellet versus mash diets containing wheat with soft and hard endosperm and only found differences in FI and WG of broilers fed on pellet diets. Soft wheat tends to produce flour with smaller surface area and relatively little starch damage due to intact starch granules, while in hard wheat particles are large with irregular shapes and starch granules are cleaved (Rose et al. 2001). Cleaved starch granules solubilise more quickly than when they are intact. Endosperm hardness may influence the quality of pellet. Hard endosperm produces good quality pellets because of large particle size and absorb more water during pelleting process which helps in gelatinisation (Abdollahi et al. 2011, 2013). However, this study was unable to detect any effect of EH on growth performance of broilers, although, there was a range (21 – 87) in relative units of EH of studied wheat samples.

The lack of association between HFN and growth performance confirmed findings of Hetland et al. (2007). The reported effect of HFN on growth performance are inconsistent (Rose et al. 2001, Svihus and Gullord 2002) and require further investigation. Hagberg falling number is used in the milling industry to access the wheat suitability for bread making, and a high HFN is considered to produce a good quality loaf for bread making. Hagberg falling number is a measure of α- amylase activity to determine pre-harvest sprouting. High α-amylase activity means less viscous wheat flour upon gelatinisation. The positive correlation between SW of wheat and FCR was interesting and in line with previous works (McCracken and Quintin

2000; Ball et al. 2013), but SW did not correlate to any of the other broiler performance attributes, so making it difficult to explain this relationship.

The absence of a relationship between growth performance and AME in this study agreed with previous findings (Steenfeldt 2001; Ball et al. 2013; Pirgozliev et al. 2015). The differences in AME of wheat samples examined in this study are not clearly related to variations in wheat chemical composition or quality characteristics. Wheat provides high proportion of ME (up to 70 %) in practical broilers diets and any differences in AME between different wheat samples are important. However, this study has confirmed that care should be taken in using wheat chemical composition and quality characteristics information as predictor of AME of individual wheat samples.

In the present experiment, there were significant differences in FI and growth rate of broilers when fed diets comprising different individual wheat samples. Broilers fed diet containing wheat sample 8 had 14.3 % and 13.8 % higher FI and WG, respectively as compared to sample 2. In this study, differences were unlikely due to differences in protein contents of wheat samples because all diets were made isonitrogenous and had same amino acid balance. This magnitude of difference in broiler growth performance would be commercially important for the broiler feed industry. Conversely, there were no differences between fifteen (15) out of seventeen (17) wheat samples. Wheat samples two (2) and seven (7) were the samples which had significant low growth rate in broilers as compared to other fifteen samples. Further examination of data indicated that these two samples did not have any obvious difference in their chemical composition and quality characteristics. Steenfeldt (2001) also reported 14 % reduction in growth rate of broilers when fed diets containing different wheat cultivars at similar inclusion (65 %) of wheat. The results of this study suggest that perhaps nutritionists can identify samples that give poor growth rate. In this study, broilers with low growth rate also had lower voluntary feed intakes. The rate of starch digestion could possibly be a factor in investigating the differences in feed intake of broiler chickens. Liu et al. (2013) have found differences in growth rate of broilers when fed diets with different rate of starch digestion.

In conclusion, the current UK wheat samples examined in this study varied in their chemical composition and quality characteristics. The results indicated that apparent metabolisable energy of currently available UK wheat samples is variable. Ideally, the AME of individual batches of wheat samples would be considered at diet formulation stage at commercial feed mills so it would require a robust prediction method. This study has not been able to specify that wheat chemical composition and quality characteristics can be used for determination of AME. The present study indicated that there was no association of wheat characteristics with AME. The study also illustrated no clear association of starch and protein with AME but would be interesting to investigate the relationship between digestibility of macronutrients and AME.

The present study has demonstrated that there are substantial differences in growth rate of broilers fed different wheat samples, although no difference in feed efficiency was identified. High growth rate in broilers is important because birds can achieve live weight gain at a faster rate resulting in a shorter production cycle. In this study, difference in FI and WG were not related to AME or any single or combination of chemical composition and quality characteristics of wheat. Differences in feed intake of broilers fed different wheat samples warrant further investigations.

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No potential conflict of interest was reported by the authors.

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Table 1. List of experimental wheat samples.

Sample ID	Variety	Growing site	Type*	Usage
1	Leeds	Nottinghamshire	Feed (Soft)	Feed wheat
2	Leeds	Yorkshire	Feed (Soft)	Feed wheat
3	Leeds	Lincolnshire	Feed (Soft)	Feed wheat
4	Leeds	Cambridgeshire	Feed (Soft)	Feed wheat
5	KWS Santiago	Yorkshire	Feed (Hard)	Feed wheat
6	KWS Santiago	Nottinghamshire	Feed (Hard)	Feed wheat
7	KWS Santiago	Lincolnshire	Feed (Hard)	Feed wheat
8	KWS Santiago	Cambridgeshire	Feed (Hard)	Feed wheat
9	KWS Lili	Yorkshire	Milling (Hard)	Bread
10	KWS Lili	Yorkshire	Milling (Hard)	Bread
11	KWS Trinity	Yorkshire	Milling (Hard)	Bread
12	KWS Trinity	Yorkshire	Milling (Hard)	Bread
13	KWS Trinity	Lincolnshire	Milling (Hard)	Bread
14	KWS Trinity	Cambridge	Milling (Hard)	Bread
15	KWS Barrel	Lincolnshire	Milling (Soft)	Cakes, biscuits
16	KWS Barrel	Cambridgeshire	Milling (Soft)	Cakes, biscuits
17	KWS Basset	Cambridgeshire	Milling (Soft)	Cakes, biscuits

*Varieties are listed on AHDB (Agriculture and horticulture development board) recommended list 2016/2017.

Table 2. Ingredient and chemical composition (g/kg as-fed) of the experimental balancer formulation.

Item	g/kg
Dietary ingredients	
Soybean meal (48)	521.3
Full fat soybean meal	299.2
Soya oil	60.5
Monocalcium phosphate	35.4
Limestone	40.9
NaCl	9.1
L-Lysine-HCL	9.1
DL Methionine	12.4
Vitamin mineral premix[1]	12.1
	1000
Calculated analysis	
CP (g/kg)	374.5
ME (MJ/kg)	12.45
Crude fat (g/kg)	119.3
Ca (g/kg)	23.3
Available P (g/kg)	9.7
Lysine (g/kg)	31.3
Methionine + Cysteine (g/kg)	20.4
Tryptophan (g/kg)	4.6
Analysed values	
DM (g/kg)	915
GE (MJ/kg)	18.03
CP (Nx6.25) (g/kg)	369
Crude Fat (g/kg)	127

The balancer was fed as a part of complete diet comprising of 645g/kg of each experimental wheat sample, mixture of wheat protein isolate and starch 25g/kg and 330g/kg of the balancer. Each experimental diet met or exceeded the diet specification for Ross 308 male broilers (Aviagen Ltd, Edinburgh, UK).

[1]The vitamin and mineral premix contained vitamins and trace elements to meet the breeder’s recommendations (Aviagen Ltd, Edinburgh, UK). The premix provided (units/kg diet): retinol, 12000 IU; cholecalciferol, 5000 IU; α-tocopherol 34mg; menadione, 3mg; thiamine, 2mg; riboflavin, 7mg; pyridoxine,5mg; cobalamin, 15µg; nicotinic acid,50mg; pantothenic acid, 15g; folic acid,1mg; biotin,200µg; 80mg Fe as iron sulphate (30%); 10µg Cu as copper sulphate (25%); 100mg Mn as manganous oxide (62%); 80mg Zn as zinc oxide (72%); 1mg I as calcium iodate (52%); 0.2mg Se as sodium selenite (4.5%) and 0.5mg Mo as sodium molybdate (40%).

Table 3. Chemical composition of seventeen wheat samples (g/kg DM).

Wheat samples	Proximate nutrient					Polysaccharide composition			
	Dry Matter	Protein	GE[1]	Fat	Ash	Starch	NSP[2]	sNSP[3]	insNSP[4]
1	873	143	18.11	10.9	19.6	678	98.2	17.9	80.2
2	905	117	17.94	16.4	16.0	704	92.8	21.3	71.5
3	882	127	17.88	12.9	15.3	704	90.5	16.2	74.2
4	887	116	17.81	12.4	12.8	696	87.7	13.8	73.9
5	904	117	17.89	16.1	15.9	697	86.6	15.1	71.4
6	877	138	18.13	14.9	17.9	722	90.6	18.4	72.2
7	898	116	17.98	17.4	16.2	671	80.1	12.3	67.8
8	890	123	17.94	13.9	18.0	728	87.7	11.2	76.4
9	898	122	18.03	15.0	16.3	699	86.7	18.8	67.9
10	904	117	18.09	14.4	15.1	704	90.7	22.6	68.2
11	910	126	18.24	12.7	16.9	707	82.2	11.3	71.0
12	904	119	18.06	15.7	16.4	727	86.9	23.2	63.7
13	891	127	18.00	15.4	14.2	708	83.5	15.9	67.6
14	893	116	17.97	15.9	14.8	715	84.7	13.6	71.1
15	886	122	18.02	17.1	14.9	704	92.9	21.7	71.2
16	902	114	17.98	11.6	15.3	709	87.5	17.3	70.3
17	891	97	17.81	14.8	17.2	726	87.4	13.9	73.5
Mean	894	121	17.99	16.0	14.6	706	88.0	16.7	71.3
CV %	1.2	8.3	0.63	9.8	13.0	2.2	4.9	23.1	5.3

[1]Gross energy (MJ/kg DM) mega joules/kilogram on dry matter.
[2]Non–starch polysaccharides.
[3]Soluble non–starch polysaccharides.
[4]insoluble non–starch polysaccharides.
CV %: represents variations between seventeen wheat samples.

Table 4. Quality characteristics of seventeen wheat samples.

Wheat samples	HFN[1]	EH[2]	SW[3] (kg/hl))	TGW[4] (g)	DV[5] (cP)	KV[6] (cSt)
1	240	35	77.8	45.7	3.4	1.56
2	233	32	82.3	52.3	6.0	1.44
3	130	26	76.6	48.6	3.9	1.32
4	210	21	78.6	52.6	4.5	1.32
5	181	87	80.0	52.4	3.4	1.29
6	291	82	75.4	46.3	4.6	1.42
7	197	71	78.1	52.6	2.6	1.17
8	241	75	81.3	52.9	2.7	1.20
9	301	85	81.8	50.9	3.6	1.39
10	308	74	80.2	50.2	3.8	1.27
11	380	79	82.4	53.2	4.4	1.42
12	374	68	79.0	55.1	4.3	1.49
13	368	64	77.2	54.7	2.8	1.42
14	384	56	80.8	59.9	2.4	1.27
15	237	30	77.1	54.4	2.8	1.30
16	252	27	82.3	59.6	2.7	1.27
17	206	31	78.7	59.4	2.5	1.30
Mean	266	55	79.4	53.0	3.5	1.34
CV %	28.7	43.7	2.8	7.8	27.5	7.71

[1]Hagberg falling numbers, [2]Endosperm hardness (relative units 0-120 soft-hard), [3]Specific weight, [4]Weight of 1000 kernels of wheat, [5]Dynamic water extract viscosity (centipoise), [6]Kinematic water extract viscosity (centistokes).

CV %: represents variations between seventeen wheat samples.

Table 5. The effect of wheat samples on [1]apparent metabolisable energy (AME MJ/kg DM), N-corrected apparent metabolisable energy (AMEn MJ/kg DM), gross energy metabolisability (GE J/J), coefficient of nitrogen retention (NR), fat digestibility (FD) and dry matter retention (DMR) (data based on total collection from 19 to 21 days of age).

Wheat samples	AME	AMEn	AME:GE	AMEn:GE	NR	FD	DMR
1	14.00[abcd]	13.65[abcd]	0.773[abc]	0.754[ab]	0.545	0.637[ab]	0.765[a]
2	14.25[abcde]	13.92[abcde]	0.794[abcd]	0.776[abc]	0.557	0.658[abc]	0.795[abc]
3	13.73[ab]	13.4[ab]	0.768[ab]	0.750[ab]	0.588	0.658[abc]	0.799[bc]
4	14.44[bcde]	14.03[bcde]	0.811[cd]	0.788[bc]	0.607	0.678[abc]	0.807[c]
5	14.38[abcde]	14.05[bcde]	0.804[bcd]	0.785[bc]	0.599	0.685[abc]	0.802[c]
6	13.82[abc]	13.44[abc]	0.762[a]	0.742[a]	0.565	0.614[a]	0.763[a]
7	14.20[abcde]	13.86[abcde]	0.790[abcd]	0.771[abc]	0.560	0.742[c]	0.768[ab]
8	13.68[a]	13.32[a]	0.762[a]	0.743[a]	0.563	0.696[abc]	0.764[a]
9	14.03[abcd]	13.64[abcd]	0.778[abc]	0.756[ab]	0.575	0.605[a]	0.781[abc]
10	14.55[de]	14.17[de]	0.804[bcd]	0.783[bc]	0.572	0.668[abc]	0.806[c]
11	14.05[abcd]	13.71[abcde]	0.770[ab]	0.752[ab]	0.559	0.672[abc]	0.767[ab]
12	14.50[cde]	14.11[cde]	0.803[bcd]	0.782[bc]	0.591	0.710[bc]	0.804[c]
13	14.36[abcde]	13.96[abcde]	0.798[abcd]	0.776[abc]	0.606	0.728[bc]	0.807[c]
14	14.05[abcd]	13.65[abcd]	0.782[abc]	0.759[abc]	0.570	0.677[abc]	0.780[abc]
15	14.81[e]	14.36[e]	0.822[d]	0.797[c]	0.597	0.742[c]	0.811[c]
16	14.40[bcde]	13.96[abcde]	0.801[abcd]	0.777[abc]	0.605	0.737[c]	0.790[abc]
17	14.36[abcde]	13.99[abcde]	0.807[bcd]	0.785[bc]	0.572	0.717[bc]	0.789[abc]
Mean	14.21	13.84	0.790	0.769	0.578	0.684	0.788
SEM[2]	0.212	0.203	0.0118	0.0113	0.0168	0.0281	0.0101
P	0.012	0.017	0.004	0.005	0.179	0.007	<0.001

[1]Each value represents mean of 8 experimental units of 6 birds each.
[2]Standard error of means.
Means within a column with no common superscripts differ significantly ($P < 0.05$).

Table 6. The [1]voluntary feed intake, growth, feed conversion ratio, and ileal digesta viscosity of broilers fed experimental wheat based diets. (Data based on feeding period from day old to 21 days of age).

Wheat samples	FI	WG	FCR	BW	Ileal viscosity
1	42.5^{bc}	34.9^{c}	1.213	0.773^{c}	2.63
2	37.7^{a}	30.4^{a}	1.235	0.679^{a}	2.16
3	39.7^{abc}	33.2^{abc}	1.211	0.738^{abc}	2.09
4	39.4^{abc}	32.1^{abc}	1.225	0.714^{abc}	1.65
5	42.3^{bc}	34.4^{c}	1.224	0.763^{c}	2.01
6	38.5^{ab}	32.0^{abc}	1.201	0.711^{abc}	2.14
7	37.5^{a}	30.8^{ab}	1.213	0.687^{ab}	1.97
8	43.1^{c}	34.6^{c}	1.232	0.766^{c}	1.61
9	42.1^{bc}	33.7^{bc}	1.243	0.748^{bc}	2.44
10	40.4^{abc}	33.2^{abc}	1.211	0.737^{abc}	2.93
11	41.8^{bc}	33.5^{bc}	1.238	0.745^{bc}	2.39
12	41.5^{abc}	34.0^{c}	1.220	0.754^{c}	2.38
13	40.1^{abc}	32.2^{abc}	1.237	0.716^{abc}	2.66
14	39.9^{abc}	32.9^{abc}	1.209	0.730^{abc}	1.75
15	41.1^{abc}	33.5^{abc}	1.197	0.743^{abc}	1.73
16	38.8^{ab}	32.1^{abc}	1.210	0.713^{abc}	1.96
17	42.2^{bc}	34.3^{c}	1.233	0.760^{c}	2.04
Mean	40.5	33.1	1.221	0.734	2.15
SEM[2]	1.21	0.92	0.0138	0.0194	0.282
P	0.013	0.023	0.478	0.022	0.062

[1]Each value represents mean of 8 experimental units of 6 birds each.
[2]Standard error of means.
Means within a column with no common superscript differ significantly ($P < 0.05$).
FI= average daily feed intake (gram/bird/day on dry mater), WG= average daily body weight gain (gram/bird/day), FCR= mortality corrected feed conversion ratio (g/g on dry matter), BW= average final body weight (kg) at d 21, Ileal digesta viscosity at d 21.

Table 7. Correlation coefficients between broiler growth performance, metabolisable energy, nutrient utilisation and chemical composition and quality characteristics of seventeen wheat samples.

	CP	Fat	Ash	Starch	NSPins	NSPsol	SW	EH	NR	FD	DMR	FI	WG	FCR	AME
CP	1														
Fat	-0.314	1													
Ash	0.414	-0.207	1												
Starch	-0.227	0.048	0.045	1											
NSPins	0.319	-0.553	0.425	-0.133	1										
NSPsol	0.128	0.194	-0.052	0.069	-0.360	1									
SW	-0.357	-0.106	-0.008	0.093	-0.141	-0.123	1								
EH	0.209	0.332	0.276	0.096	-0.408	-0.104	0.164	1							
NR	-0.292	0.031	-0.737	0.146	-0.350	0.126	-0.156	-0.232	1						
FD	-0.511	0.282	-0.345	0.038	-0.289	-0.152	-0.039	-0.254	0.450	1					
DMR	-0.386	0.222	-0.744	0.080	-0.383	0.484	-0.121	-0.346	0.773	0.348	1				
FI	0.049	-0.215	0.410	0.240	0.267	-0.115	0.155	0.252	-0.062	-0.102	-0.074	1			
WG	0.101	-0.293	0.438	0.237	0.329	-0.054	0.004	0.169	0.043	-0.121	-0.070	**0.953**	1		
FCR	-0.225	-0.043	0.038	0.122	-0.095	-0.301	**0.515**	0.238	-0.079	-0.142	-0.042	0.333	0.087	1	
AME	-0.472	0.319	**-0.513**	-0.099	-0.466	0.471	0.002	-0.239	**0.534**	**0.560**	**0.730**	-0.069	-0.101	-0.153	1
AMEn	-0.481	0.341	**-0.489**	-0.132	-0.464	0.460	0.013	-0.214	**0.496**	**0.552**	**0.726**	-0.068	-0.104	-0.122	0.995

df = 15; Correlation coefficients > 0.412, 0.482, 0.606, 0.725 are statistically significant at $P < 0.1$, $P < 0.05$, $P < 0.01$, $P < 0.001$, respectively.
Significant correlations are presented in bold.
CP, NSPins, NSPsol, SW, EH: crude protein, insoluble and soluble non-starch polysaccharides, specific weight and endosperm hardness of seventeen wheat samples.
NR, FD, DMR: coefficients of nitrogen retention, fat digestibility and dry matter retention of wheat samples.
FI, WG, FCR: feed intake, weight gain, feed conversion ratio.
AME, AMEn: apparent metabolisable energy, N corrected apparent metabolisable energy of wheat samples.