Original scientific paper
Journal of Central European Agriculture, 2025, 26(2), p.293-304
DOI: /10.5513/JCEA01/26.2.4683

Assessing the feeding value of wheat for broilers

Marko TUKŠA[1] (✉), Stephen C. MANSBRIDGE[1], Isobel M. WHITING[1], Antonija ŠIMIĆ[1], Michael R. BEDFORD[2], Stephen P. ROSE[1], Vasil R. PIRGOZLIEV[1]

[1] The National Institute of Poultry Husbandry, Harper Adams University, Edgmond, Newport, Shropshire, TF10 8NB, UK
[2] AB Vista, Woodstock Court, Blenheim Road, Marlborough Business Park, Marlborough, Wiltshire SN8 4AN, UK

✉ Corresponding author: mtuksa@live.harper.ac.uk

Received: January 26, 2025; accepted: March 21, 2025

ABSTRACT

The study aimed to compare different methods assessing the nutritive value of wheat grain for broiler chickens, measured as growth performance, including wheat chemical composition, metabolizable energy (ME), starch digestibility (SD) and rate of starch digestion (RSD). Samples from wheat cultivars Bennington and Siskin were chosen for the study due to their different fibre but similar starch contents. Two cold pelleted diets including 630 g/kg of each of the wheat cultivar samples were fed *ad libitum* to broiler chickens 7 to 28 days of age to male Ross 308 broiler chickens. Each diet was fed to 16 raised floor pens following complete randomisation. Birds fed a diet based on Bennington were heavier, ate more and grew faster than those fed a Siskin-based diet (P<0.001). Bennington-fed birds tended (P<0.01) to have a lower feed conversion ratio (FCR). The diet based on Bennington had greater ME (P<0.05) than those based on Siskin, but no differences (P>0.05) in nitrogen and fat retention coefficients were observed (P>0.05). Compared to Siskin, Bennington-based diet had greater SD in proximal (P=0.017) and distal (P=0.050) ileal segments, but no differences were detected in RSD (P>0.05). Bennington-fed birds had greater daily consumption of ME, dry matter, fat, starch (P<0.001) and nitrogen (P=0.007). The results suggest that in this study not RSD but ME and intake of digestible nutrients described better the feeding value of wheat for broilers.

Keywords: non-starch polysaccharide, rate of starch digestion, broiler

INTRODUCTION

Cereal grains are the main dietary source of energy and plant proteins, as about 41% of grains are used for human consumption, 35% are used for animal feed, 18% for other uses, and the rest are used for seed or are lost (Poutanen et al., 2022). After maize, wheat is the world's second-most grown cereal crop and the largest crop in Europe, grown on more than 61.4 million hectares yielding 269 million tonnes per annum (FAO 2023). In many countries, wheat is often the only cereal used in poultry dietary formulations (Wiseman et al., 2000), so its nutritional value and variations in its feeding quality have large commercial importance.

The feeding value of wheat is variable (Steenfeldt, 2001; Azhar et al., 2019). Wheat is incorporated in broiler diets, primarily for its metabolizable energy (ME) content. However, a literature survey shows that the ME in wheat may vary considerably between 8.5 and 16.4 MJ/kg DM (McNab, 1991; Wiseman, 2000; Ravindran and Amerah, 2009). This large variation in the ME content of wheat makes it challenging for nutritionists to formulate diets for broilers.

Although using the ME system to evaluate the feeding quality of diets for poultry is widely adopted, there is not always a relationship between ME and bird growth performance or dietary chemical composition (Rose et al., 2001; Pirgozliev et al., 2003; Azhar et al., 2019). Thus, there is no conclusive information on how the chemical composition and quality characteristics of wheat are related to ME and the growth performance of birds. The most important source of energy in wheat is starch (Svihus, 2011), and it has been reported that the digestibility of starch and rate of starch digestion (RSD) (Gutierrez del Alamo et al., 2009; Selle et al., 2021) play an important role in growth performance of birds, thus suggesting that RSD may be used to describe feeding value of wheat. Starch digestion is well correlated with ME (Wiseman et al., 2000; Carré, 2004), but the RSD and progression from starch to glucose and its influence on the metabolism of nutrition is not well understood (Liu et al., 2013; Selle and Liu, 2019). Feeding wheat with varying RSD could significantly alter nutrient delivery to different parts of the gastrointestinal tract (GIT) by influencing the synchronisation of starch and protein digestion. If the starch is digested more slowly, glucose will likely be the source of energy in the lower section of the GIT and as a result spare catabolism of amino acids for energy provision in distal parts of the small intestine (Enting et al., 2005; Selle et al., 2021). Dietary fibres are taken less into consideration when formulating diets for poultry (Nguyen et al., 2021). However, the main dietary components, cereals, e.g. wheat, and soyabean meal, may contain around 10% and 20% of non-starch polysaccharides (NSP), respectively (Choct, 2015), which would vary depending on cultivar, agronomy, season, processing etc., bringing those variations to the diet. Dietary soluble NSP (sNSP), coming primarily from wheat, may increase digesta viscosity (Bedford, 1996; Pirgozliev et al., 2023), hence compromising digestion of all nutrients including starch (Refstie et al., 1999) and reducing growth. Higher digesta viscosity can slow down the passage rate through the small intestine of broiler chicken and hinder the effect of endogenous digestive enzymes, therefore, increasing the time needed for digestion and lowering starch digestion (Bedford, 2006). However, there is a lack of information on the impact of dietary fibre content on dietary RSD for broilers. Thus, the aim of this experiment was to compare the growth performance variables of broiler chickens fed two isocaloric and isonitrogenic wheat-based diets with different NSP contents with dietary RSD. It has been hypothesized that RSD may describe better the feeding values of poultry feed compared to ME. The chemical composition of the wheat samples, dietary ME, nutrient retention coefficients and intake of dietary nutrients were also determined and compared to bird growth.

MATERIALS AND METHODS

The experiment was conducted at the National Institute of Poultry Husbandry and study protocol (Project number 0806-202010-PGMPHD) was approved on 07 November 2020, by the Research Ethics Committee of Harper Adams University (UK). The experiment has been designed to comply with the ARRIVE 2.0 guidelines (Percie du Sert et al. 2020).

Wheat cultivar samples and diet preparation

Five different autumn-sown wheat cultivar samples were obtained from the market (G O Davies, Westbury LTD, Harvest House) during the 2016/17 season (Table 1). The supplier got all the cultivars from around the Midlands, UK.

Wheat cultivar samples Bennington and Siskin were chosen between the 5 wheat cultivars, as Bennington had the lowest and Siskin the highest amount of sNSP but they did not differ in starch content (Table 2).

DOI: /10.5513/JCEA01/26.2.4683

Table 1. List of wheat cultivar samples

Variety	Endosperm*	Main usage	Harvest	Area/field
Siskin	Hard	Bread	2017	The Midlands, UK
JB Diego	Hard	Feed	2017	The Midlands, UK
Graham	Soft	Feed	2017	The Midlands, UK
Zyatt	Hard	Bread	2017	The Midlands, UK
Bennington	Soft	Feed/Cakes and Pastry	2017	The Midlands, UK

* Varieties are listed in AHDB (Agriculture and Horticulture Development Board)

Table 2. Non-starch polysaccharide (NSP) composition and proximal analysis of wheat cultivars* (g/kg)

	Siskin	JB Diego	Graham	Zyatt	Bennington
Soluble NSP					
Rhamnose	0.13	0.11	0.0	0.11	0.20
Fucose	0.23	0.23	0.44	0.26	0.04
Arabinose	7.9	7.5	7.4	7.9	6.5
Xylose	11.3	11.5	9.3	11.3	8.9
Mannose	3.0	2.4	2.6	2.7	1.5
Galactose	3.6	2.9	3.0	2.9	1.4
Glucose	5.6	4.5	4.8	5.4	4.7
Glucuronic acid	0.20	0.0	0.0	0.0	0.0
Galacturonic acid	0.0	0.0	0.0	0.0	0.0
Total soluble NSP	31.8	29.1	27.7	30.4	23.3
Insoluble NSP					
Rhamnose	0.0	0.0	0.0	0.0	0.27
Fucose	0.0	0.0	0.0	0.0	0.0
Arabinose	12.4	12.7	11.4	13.7	13.4
Xylose	19.3	19.8	16.4	21.0	20.0
Mannose	1.8	1.4	2.0	1.8	2.6
Galactose	1.1	0.91	0.94	1.0	0.67
Glucose	17.4	19.0	15.0	18.4	18.9
Glucuronic acid	0.0	0.0	0.0	0.0	0.0
Galacturonic acid	0.0	0.0	0.0	0.0	0.0
Total insoluble NSP	51.9	53.8	45.8	55.9	55.8

DOI: /10.5513/JCEA01/26.2.4683

Continued. Table 2

	Siskin	JB Diego	Graham	Zyatt	Bennington
Total NSP					
Rhamnose	0.13	0.11	0.0	0.11	0.47
Fucose	0.23	0.23	0.44	0.26	0.0
Arabinose	20.2	20.2	18.8	21.6	19.9
Xylose	30.5	31.2	25.8	32.3	28.8
Mannose	4.7	3.8	4.6	4.4	4.1
Galactose	4.6	3.8	3.9	3.9	2.1
Glucose	23.0	23.5	19.8	23.8	23.6
Glucuronic acid	0.20	0.0	0.0	0.0	0.0
Galacturonic acid	0.0	0.0	0.0	0.0	0.0
Total NSP	83.7	82.9	73.4	86.3	79.0
Starch	564	623.2	654.5	624.7	569
Protein	112	113	112	116	98.6
Fat	6.8	10.1	12.3	9.8	14.7
Gross energy (MJ/kg DM)	15.78	15.96	16.00	16.08	15.62
Dry matter	882.7	894.7	886.5	987.5	879.9

NSP (Non-starch polysaccharides); *Analysed in technical duplicates.

After milling, 630 g/kg of each wheat sample was mixed with 370 g/kg of balancer feed (Table 3).

The proximate analysis of the diets is shown in Table 4. Additionally, titanium dioxide (TiO_2) was added to the diets in the amount of 5 g/kg diet as an indigestible marker to determine the digestibility of nutrients. Finally, diets were pelleted at the site using a no-steam pelletizer (KAHL, Amandus Kahl GmbH & Co. KG, Reinbek, Germany) with diameter and length of pellets 3 mm and 5 mm respectively. Pelleting was maintained at a temperature of around 50 °C.

Poultry care and housing

The experiment was carried out at the National Institute of Poultry Husbandry (Edgmont, Shropshire, UK) which is located at Harper Adams University. The study lasted for 28 days and included one hundred and ninety-eight (198) Ross 308 male broilers supplied by a local commercial hatchery (Cyril Bason Ltd, Craven Arms, UK). To ensure a good start to performance, the birds were fed from 0 to 7 days with a starter diet following the breeder's recommendations (Aviage Ltd, Edinburgh, UK) and rear in a one-floor pen. From day 7, the first day of the experimental phase, birds were separated into 32 raised pens with 6 birds in each pen. All pens were equipped with feeders and drinkers. Diets were fed as pellets, with *ad libitum* access to feed and water. Each of the thirty-two pens had a solid floor with an area of 60 × 60 cm covered with cardboard and wood shavings. Each diet was fed to 16 pens following randomisation. The room where the birds were housed was environmentally controlled with a starting temperature of 32 °C which was reduced slightly every day until day 21 when the temperature was 21 °C. The room also had an automatic lighting schedule, with

Table 3. Balancer diet used to prepare complete diets with wheat cultivar samples

Ingredient	Amount (g/kg)
Soybean meal (48)	700.0
Full-fat soybean meal	140.0
Soya oil	70.0
Monocalcium phosphate	30.0
Limestone	30.0
NaCl	10.0
DL-Methionine	10.0
Vitamin mineral premix[1]	10.8
Calculated analysis (as-fed basis)	
CP	392.9
ME (MJ/kg)	12.07
Crude fat	106.2
Ca	21.4
Available P	8.5
Lysine	25.9
Methionine + Cysteine	21.1
Tryptophan	4.9
Analysed values (DM basis)[2]	
DM	917.4
GE (MJ/kg)	16.62
CP	368.8
OIL	95.3
Starch	65

CP (Crude protein); ME (Metabolizable energy); DM (Dry matter); GE (Gross energy).

The balancer was fed as a part of a complete diet comprising of 630 g/kg of each experimental wheat sample and 370 g/kg of the balancer. Each experimental diet met or exceeded the diet specification for Ross 308 male broilers (Aviagen, 2022).

[1] The vitamin and mineral premix contained vitamins and trace elements to meet the breeder's recommendations (Aviagen, 2022). The premix provided (units/kg diet): retinol, 12 000 IU; cholecalciferol, 5000 IU; α-tocopherol 34 mg; menadione, 3 mg; thiamine, 2 mg; riboflavin, 7 mg; pyridoxine,5 mg; cobalamin, 15 µg; nicotinic acid,50 mg; pantothenic acid, 15 g; folic acid,1 mg; biotin,200 µg; 80 mg Fe as iron sulphate (30%); 10 µg Cu as copper sulphate (25%); 100 mg Mn as manganous oxide (62%); 80 mg Zn as zinc oxide (72%); 1 mg I as calcium iodate (52%); 0.2 mg Se as sodium selenite (4.5%) and 0.5 mg Mo as sodium molybdate (40%).

[2] Analysed in technical duplicates.

Table 4. Analysed values of the wheat-based diets

Values	Siskin Diet	Bennington Diet
DM (g/kg)	895.6	878.3
GE (MJ/kg)	15.78	15.62
Starch (g/kg)	379.4	382.5
CP (g/kg)	207.0	198.6
Fat (g/kg)	39.54	44.52

DM (Dry matter); GE (Gross energy); CP (Crude protein)

the light:dark ratio decreasing from 23:1 hours at the day-old, to 18:6 hours for seven-day-old birds (Aviagen Ltd., Edinburgh, UK). Birds were checked twice a day, and health and mortality were recorded.

Data collection and sampling

All birds from each pen were weighed per pen basis on the first and the last day of the experiment to obtain the data necessary to calculate body weight gain (WG). The weight of the feed was also measured separately for each pen during the same period to get the data on total feed intake (FI). Those values were used to calculate the feed conversion ratio (FCR). There were no dead birds throughout the experimental phase. This experiment required data on the last 24h feed intake (FI_{24}) which is important to calculate mean retention time (MRT).

On day 26, plastic trays were placed underneath the raised pens and the solid floor was replaced with the wire mesh floor to enable the excreta collection. Excreta was collected for 2 consecutive days and on the morning of day 28 all trays were removed and excreta was scooped into the aluminium container marked with pen numbers and placed into the oven at 60 °C until the constant weight. Afterwards, excreta was milled using a Retsch ZM 200 laboratory mill (Retsch GmbH, Haan, Germany) with a 0.75 mm screen, stored in plastic bags and prepared for laboratory analysis of TiO_2, gross energy (GE), dry matter (DM), nitrogen (N) and fats. At the end of the study, all birds were head-only electrically stunned and killed by cervical dislocation, dissected and the small intestine was removed. The jejunum and ileum were divided at Meckel's diverticulum, and each of them was split into two halves of the same length. Digesta samples were taken manually from proximal and distal jejunum and proximal and distal ileum, pooled per pen and stored on ice in plastic containers. Once frozen, samples were placed in a freeze-dryer for a few days until all water content was removed, weighed and milled. Prepared samples were analysed for TiO_2, N and starch.

Analysis of feed ingredients, excreta and digesta samples

Dry matter in wheat samples, balancer feed and excreta was determined by drying in a forced draft oven at 105 °C to a constant weight (AOAC, 2000). Leco FF-828 machine (Leco Corp., St. Josep, MI) was used for measuring N in wheat samples, balancer diet, excreta and digesta. A coefficient of 6.25 was multiplied by the amount of N in each sample to get the amount of CP. For calculating the GE content of samples, an adiabatic bomb calorimeter (Parr 6200 Instrument Company, Moline, IL, 61,265, United States) was used as described elsewhere (Pirgozliev et al., 2006). The NSP in wheat were determined as described by Englyst and Cummings (1988). The amount of starch and TiO_2 in diet, excreta and digesta were analysed in the external laboratory (DM Scientific Ltd, Dalton, New Yorkshire). Starch was analysed using the polarimetric method following Commission Regulation (EC No 152/2009), and TiO_2 using a UV VIS spectrometer at 408nm following the method developed by Peddie et al. (1982).

Calculation of ME and digestibility coefficients

For the calculation of dietary ME, the nitrogen-corrected apparent metabolizable energy was used (Hill and Anderson, 1958):

$$ME = GE\ Diet - \frac{(GE\ Excreta \times Ti\ Diet)}{Ti\ Excreta} - 34.39 \times N\ retained$$

where the value of 34.39 (MJ/kg) represents the energy values of uric acid and

$$Nretained = N\ diet - \frac{(N\ excreta \times TiO_2\ diet)}{TiO_2\ excreta}$$

Starch digestibility (SD) was calculated in each part of the small intestine using the concentration of starch and TiO_2 that were analysed from digesta samples and diets (McDonald et al.,1994). The equation used is as follows:

$$\mathrm{SD} = \frac{(starch \div TiO_2)\ diet - (starch \div TiO_2)\ digesta}{(starch \div TiO_2)\ diet}$$

where (starch) diet is the amount of starch (g/kg) in the diet, and (starch) digesta is the amount of starch (g/kg) in each part of the small intestine digesta. The same is for TiO_2 (g/kg). Instead of TiO_2, any other digestibility marker can be used and the equation is the same. The total amount of starch should be lower in the distal part of the intestine and SD should have the highest values in the distal ileum. The retention coefficient of fat (FR), nitrogen (NR) and DM (DMR) were calculated using the same equation but instead of digesta the excreta values were used.

Calculation of RSD and MRT

The RSD was calculated using Sigma Plot (Systat Software Inc). The exponential, non-linear regression was described by a model developed by Ørskov and McDonald (1979):

$$SD = DST \times (1 - e^{-rsd \times t})$$

To calculate the rate of starch digestion using Sigma Plot (Systat Software Inc), the SD had to be calculated as previously described, and time (t) which is MRT in each segment, using the equation (Weurding et al., 2001):

$$MRT(min) = \frac{1440\ \times TiO_2\ digesta\ \times W}{FI\ 24h\ \times TiO_2\ diet}$$

In the equation TiO_2 digesta is the amount of marker (g/kg) in each segment of the small intestine (Proximal and Distal Jejunum and Proximal and Distal Ileum), W is the weight (g) of dry, milled content of each part of the small intestine, FI_{24} is feed intake over last 24h, TiO_2 diet is the amount of marker (g/kg) in the diet and the number 1440 is the total amount of minutes in 24h.

Statistical Analysis

Statistical comparisons were performed using one-way ANOVA procedure of Genstat 23rd edition (VSN International Ltd) testing for the main effects of the two wheat cultivar samples. Differences were considered significant at *P*<0.05.

RESULTS

The results on wheat NSP and dietary chemical composition are presented in Tables 2, 3 and 4. In wheat samples, the mean total NSP was 81.1 g/kg, with the lowest at 73.4 g/kg (cv Graham) and the highest at 86.3 g/kg (cv Zyatt) (Table 2). The average sNSP content was 28.5 g/kg, as cultivar Benington had the lowest (23.3 g/kg) and cultivar Siskin had the highest (31.8 g/kg) sNSP content. Cultivars Zyatt and Bennington had the highest insoluble NSP (iNSP) content (55.9 and 55.8 g/kg, respectively) although cv Graham had the lowest one (45.8 g/kg). The main sNSP sugar fraction was xylose (10.5 g/kg) with the lowest at 8.9 g/kg (Bennington) and the highest at 11.5 g/kg (JB Diego). Xylose was also the main carbohydrate constituent determined in the insoluble (average 19.3 g/kg; with the lowest 16.4 g/kg, Graham; highest 21.0 g/kg, Zyatt) and in the total (average 29.7 g/kg; Graham lowest 25.8 g/kg and Zyatt highest 32.3 g/kg) fractions.The average starch content was 607 g/kgas cultivar Graham had the greatest starch content of 654.5 g/kg. Cultivars Bennington and Siskin had very similar starch content (569 vs 564 g/kg). Cultivar Bennington contained 98.6 g/kg CP (lowest) and Zyatt contained 116.0 g/kg CP (highest). There was a range of fat content with 6.8 g/kg the lowest (Siskin) and 14.7 g/kg the highest (Bennington). The chemical composition of the two experimental diets after mixing 630 g of balancer with 370 g of each of the two chosen wheat samples is provided in Table 4. The starch content in the two diets was almost identical although the diet based on Bennington had about 8 g lower CP.

Results on growth performance are presented in Table 5. The average weight of the birds at 28 days of age was 1059 g compared to 1739 g expected by breeders' recommendations (Aviagen Ltd, Edinburgh, UK, 2022), i.e. 39% lower. Birds fed Bennington were 119 g heavier than those fed a Siskin-based diet (*P*<0.001). Similarly, broilers fed Bennington had 10.2% greater FI (*P*<0.001) and grew faster, e.g. 12% greater WG (*P*<0.001), compared to Siskin-fed birds. The same birds tended (*P*<0.01) to have lower FCR.

The diet based on cultivar Bennington had greater ME (*P*<0.05) and tended (*P*=0.51) to have a greater DMR coefficient (Table 6). No differences (*P*>0.05) in N retention and fat retention coefficients of diets were observed (Table 6).

A diet formulated with cultivar Bennington had greater SD in proximal (*P*=0.017) and distal (*P*=0.050) ileal segments, but no differences were detected in the jejunum (Table 7).

Table 5. The effect of wheat samples on growth performance

Treatment	FI (g/b/d DM)	WG (g/b/d)	FCR (DM)	BW (day 7)	BW (day 28)
Wheat					
Bennington	61.8	46.6	1.330	139.5	1118.0
Siskin	55.5	41.0	1.354	138.6	999.0
SEM	1.12	0.89	0.0133	0.38	18.7
Significance					
P - value	<0.001	<0.001	0.077	0.096	<0.001

FI (Feed intake); WG (Weight gain); FCR (Feed conversion ratio); BW (Body weight); SEM (Standard error of means)

Table 6. The effect of wheat samples on available energy retention coefficients

Treatment	ME (MJ/kg DM)	DMR	NR	FR
Wheat				
Bennington	12.89	0.748	0.632	0.700
Siskin	12.53	0.730	0.618	0.646
SEM	0.118	0.0060	0.0105	0.0296
Significance				
P - value	0.047	0.051	0.359	0.213

ME (nitrogen-corrected apparent metabolizable energy); DMR (Dry matter retention); NR (Nitrogen retention); FR (Fat retention); SEM (Standard error of means)

Table 7. Starch digestibility (SD) values in each part of the small intestine

Treatment	Jejunum		Ileum	
	Proximal	Distal	Proximal	Distal
Wheat				
Bennington	0.771	0.859	0.925	0.925
Siskin	0.754	0.858	0.911	0.919
SEM	0.0099	0.0091	0.00399	0.00192
Significance				
P - value	0.242	0.935	0.017	0.050

SEM (Standard error of means)

Table 8 contains results on the daily intake of ME and digestible nutrients. Birds fed diets containing Bennington consumed daily more ME, DM, fat, starch ($P<0.001$) and N ($P=0.007$) compared to birds fed Siskin based diet.

The results of MRT and RSD through the small intestine are presented in Table 9. The only significant difference ($P=0.041$) was for the greater MRT in the distal ileal segment in birds.

The RSD for both diets did not differ significantly ($P>0.05$). The RSD curve showed that almost 80% of the starch in the small intestine is digested in the first 30 to 40 minutes in both diets, which all occur in the jejunum, with a rapid fall in digestion rate afterwards. During the remaining period in the ileum, starch digestion rises slightly and reaches a maximum of between 90-95% at the end of the small intestine (Figures 1 & 2).

Table 8. Intake of available energy and major nutrients

Treatment	ME intake	DMi	Ni	Fi	Si
Wheat					
Bennington	0.79	45.69	1.61	1.85	20.56
Siskin	0.69	41.25	1.50	1.47	18.23
SEM	0.012	0.833	0.026	0.063	0.310
Significance					
P - value	<0.001	<0.001	0.007	<0.001	<0.001

ME (nitrogen-corrected apparent metabolizable energy); DMi (Dry matter intake); Ni (Nitrogen intake); Fi (Fat intake); Si (Starch intake); SEM (Standard error of means)

Table 9. Mean retention time (MRT min^{-1}) and the rate of starch digestion (RSD h^{-1}) through the small intestine

Treatment	Jejunum (MRT)		Ileum (MRT)		Total (MRT)	RSD (h^{-1})
	Proximal	Distal	Proximal	Distal	All segments	
Wheat						
Bennington	23.33	47.8	65.0	74.4	210.7	2.742
Siskin	24.04	47.4	59.3	65.0	196.7	2.589
SEM	1.343	3.01	2.83	3.05	7.43	0.117
Significance						
P - value	0.714	0.916	0.136	0.041	0.196	0.205

MRT (Mean retention time); RSD (Rate of starch digestion); SEM (Standard error of means)

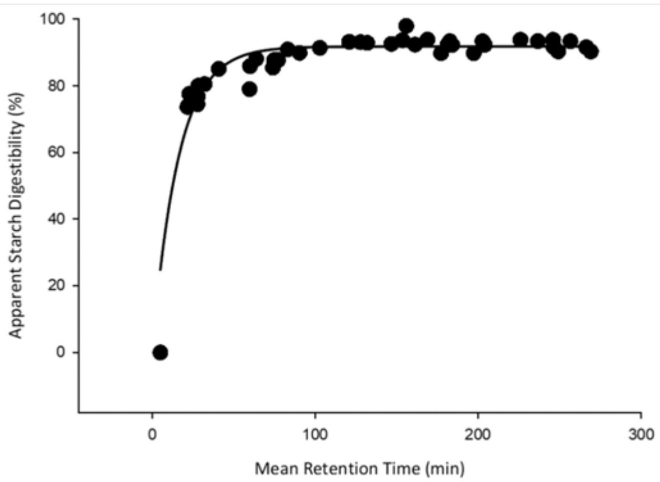

Figure 1. Rate of starch digestion curve of the experimental diet Bennington

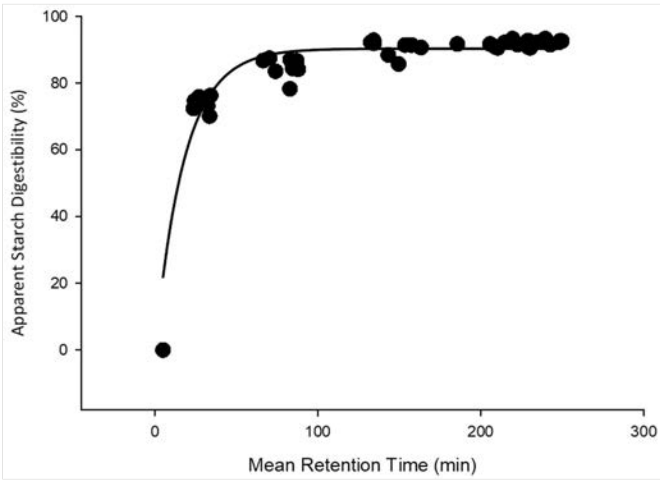

Figure 2. Rate of starch digestion of the experimental diet Siskin

DISCUSSION

The aim of the study was to determine the chemical composition of wheat cultivar samples, dietary ME and RSD and to assess which variable can best describe the growth performance of the birds.

All birds remained healthy and there were no mortalities during the study but the overall weight of the birds at the end of the study was 39% lower than breeders recommendations (Aviagen Ltd., Edinburgh, UK). This was possibly due to a combination of frequent weighing, being fed a mash starter and cold pelleted grower diets, rather than steam pelleted feed and being kept in small groups (Pirgozliev et al., 2016; Yang et al., 2020). This was not considered to be detrimental to the experimental objectives.

Birds fed the cultivar Bennington had greater FI and WG that correspond to greater ME, ileal SD and intake of digestible nutrients. However, the slightly greater dietary fat content, i.e. 5 g/kg, of Bennington based diet may also have contributed to improve palatability. In addition, wheat cultivar Bennington had lower NSP content. Whiting et al. (2023) also found an improved FI and WG in birds fed Bennington compared to a Siskin-based diet. Interestingly, there was no difference in RSD between the two diets.

The primary sources of energy in wheat are starch and protein, and to a much lesser extent fats, and it would make sense that their content and digestibility values are closely related to ME (McCracken et al., 2002; Svihus and Gullord, 2002; Pirgozliev et al., 2003). Although the fat content of the Bennington-based diet was 11.2% greater the difference in ME was 2.8% only. Thus, as expected, the differences in fat content may only partially explain the observed differences in ME between the diets. In this experiment, a diet based on the cultivar Bennington also resulted in higher ileal starch digestibility values and the close relationship between the digestibility of starch and ME has been reported before (Carré, 2004; Svihus, 2014). In addition, it has been reported (Bedford and Classen, 1992; Chobanova et al., 2023) that feeding diets containing high fibre/NSP may cause higher digesta viscosity, decreasing dietary AME, and nutrient availability, thus lowering the growth performance of broiler chicken. Several studies (Choct, 1997; 2015; Gutiérrez-Alamo et al., 2008; Pirgozliev et al., 2015) have reported that total and soluble NSP negatively affect the ME of the wheat which agrees with the finding of this study.

However, the relationship between ME and growth performance is inconsistent across all studies with the result that ME alone cannot be used as the value to predict the performance of broilers (Wiseman, 2000; Pirgozliev et al., 2006). The findings of this study demonstrate that the intake of digestible nutrients rather than nutrient digestibility alone is more reliable for predicting growth performance. Intake of the Bennington diet, particularly in terms of DM, ME, starch and nitrogen can explain the superior growth outcome observed.

Diets with equal amounts of nutrients but with different kinetics of digestion may well result in different performance outcomes. Differences in the RSD were studied by Gutierrez del Alamo et al. (2009), but the reason for these differences was not understood. Research by Liu et al. (2013) and Selle and Liu (2019), suggested that starch and protein digestion kinetics must be in balance for optimal performance, and if starch is broken down too quickly, the bird will start using amino acids as a source of energy for protein synthesis in the lower section of the small intestine. Azhar et al. (2019) reported that wheat samples with higher RSD values stimulated higher FI and growth performance. Although there was a difference in FI between birds fed the two diets, the difference in RSD was numerical only. Values were in a similar range to that reported previously (Gutierrez del Alamo et al., 2009) for wheat-based diets, where the author found a range of 2.45 to 3.28 h^{-1} and also reported that lower RSD values resulted in poorer growth performance. While the work of Gutierrez del Alamo et al. (2009) showed that more rapid RSD is associated with greater performance and ME, research by Selle et al. (2021) has suggested that slower starch digestion could be beneficial if it were to reduce the catabolism of amino acids in the gut mucosa for energy provision in distal parts of the small intestine. The improved ileal starch digestibility is most likely due to lower NSPs and an increase in ileal MRT in the Bennington wheat diet. Differences in endosperm hardness may also be a reason for different starch digestibility and broiler growth performance, although there are confounding reports associated with dietary processing, i.e. feeding mash or pelleted diets (Carre et al., 2005; Pirgozliev et al., 2016). However, research by Hetland et al. (2007) and more recently, Azhar et al. (2019) did not find any relationship between EH and ME of bird growth performances. It can be anticipated that fast RSD could stimulate FI in birds as the most abundant nutrient is removed and space is made for the inflow of new digesta. However, despite the difference in FI, there were no differences in total MRT and RSD between the two experimental diets, thus questioning this hypothesis.

Anyway, ileal SD and the daily intake of energy and digestible nutrients seem to provide a more robust and logical explanation for the observed difference in growth performance results. It may be that the higher NSPs in Suskin reduced the efficiency of nutrient absorption in the small intestine, although no impact of RSD was observed.

CONCLUSION

The results from this study showed that compared to RSD, information on dietary ME and intake of digestible nutrients explained better growth performance of broiler chickens. This suggests that the daily intake of digestible nutrients rather than the coefficient of digestibility of the nutrients per se or even the rate of their digestion is most important. In the absence of feed intake data, information on digestibility data only has limited value in describing the feeding quality of diets. Thus, practical research including feed intake and nutrient digestibility data is warranted.

REFERENCES

AOAC (2000) Official Methods of Analysis of the Association of Agricultural Chemists. 17th ed. Washington, DC: Association of Official Analytical Chemists.

Aviagen (2022) Available at: https://eu.aviagen.com/assets/Tech_Center/Ross_Broiler/Ross-BroilerNutritionSpecifications2022-EN.pdf [Accessed 12 February 2025]

Azhar, M.R., Rose, S.P., Mackenzie, A.M., Mansbridge, S.C., Bedford, M.R., Lovegrove, A., Pirgozliev, V.R. (2019) Wheat sample affects growth performance and the apparent metabolisable energy value for broiler chickens. British Poultry Science, 60, 457-466. DOI: https://doi.org/10.1080/00071668.2019.1605152

Bedford, M.R. (2006) Effect of non-starch polysaccharidases on avian gastrointestinal function. Avian gut function in health and disease. Oxon: Wallingford, pp. 159-170.

Bedford, M.R. (1996) The Effect of enzymes on digestion. Journal of Applied Poultry Research, 5, 370-378. DOI: https://doi.org/10.1093/japr/5.4.370

Bedford, M.R., Classen, H.L. (1992) Reduction of intestinal viscosity through manipulation of dietary rye and pentosanase concentration is effected through changes in the carbohydrate composition of the intestinal aqueous phase and results in improved growth rate and food conversion efficiency of broiler chicks. The Journal of Nutrition, 122, 560-569. DOI: https://doi.org/10.1093/jn/122.3.560

Carré, B., 2004. Causes for variation in digestibility of starch among feedstuffs. World's Poultry Science Journal, 60, 76-89. DOI: https://doi.org/10.1079/WPS20036

Carré, B., Muley, N., Gomez, J., Oury, F.X., Laffitte, E., Guillou, D., Signoret, C. (2005) Soft wheat instead of hard wheat in pelleted diets results in high starch digestibility in broiler chickens. British Poultry Science, 46(1), 66-74. DOI: https://doi.org/10.1080/00071660400023847

Chobanova, S., Karkelanov, N., Mansbridge, S.C., Whiting, I.M., Simic, A., Rose, S.P., Pirgozliev, V.R. (2023) Defatted black soldier fly larvae meal as an alternative to soybean meal for broiler chickens. Poultry, 2(3), 430-441. DOI: https://doi.org/10.3390/poultry2030032

Choct, M. (2015) Feed non-starch polysaccharides for monogastric animals: classification and function. Animal Production Science, 55, 1360-1366. DOI: https://doi.org/10.1071/AN15276

Choct, M. (1997) 1 Feed Non-Starch Polysaccharides: Chemical Structures and Nutritional Significance. Feed milling international, 191 (1), 13-26.

Englyst, H.N., Cummings, J.H. (1988) Improved method for measurement of dietary fiber as non-starch polysaccharides in plant foods. Journal of Association of Official Analytical Chemists, 71, 808-814. DOI: https://doi.org/10.1093/jaoac/71.4.808

Enting, H., Pos, J., Weurding, R.E., Veldman, A. (2005) Starch digestion rate affects broiler performance. Proceedings of the 17th Australian Poultry Science Symposium, Sydney, New South Wales, Australia, 7-9 February, 17-20.

Hetland, H., Uhlen, A.K., Viken, K.H.K., Krekling, T., Svihus, B. (2007) Hagberg falling number and the nutritional value of wheat in broiler chicken diets. British Poultry Science, 48 (1), 12-20. DOI: https://doi.org/10.1080/00071660601045763

FAO (2023) FAOSTAT Database. Food and Agriculture Organization of the United Nations. Available at: http://faostat3.fao.org/home/E [Accessed 12 February 2025]

Gutierrez del Alamo, A.G., Verstegen, M.W.A., Den Hartog, L.A., de Ayala, P.P., Villamide, M.J. (2009) Wheat starch digestion rate affects broiler performance. Poultry Science, 88, 1666-1675. DOI: https://doi.org/10.3382/ps.2008-00502

Gutiérrez-Alamo, A., De Ayala, P.P., Verstegen, M.W.A., Den Hartog, L.A., Villamide, M.J. (2008) Variability in wheat: factors affecting its nutritional value. World's Poultry Science Journal, 64, 20-39. DOI: https://doi.org/10.1017/S0043933907001699

Hill, F.W., Anderson, D.L. (1958) Comparison of metabolizable energy and productive energy determinations with growing chicks. Journal of Nutrition, 64, 587-603.

Liu, S.Y., Selle, P.H., Cowieson, A.J., Liu, S.Y., Selle, P.H., Cowieson, A.J. (2013) The kinetics of starch and nitrogen digestion regulate growth performance and nutrient utilisation of broilers fed coarsely ground, sorghum-based diets. Animal Production and Science, 53, 1033-1040. DOI: https://doi.org/10.1071/AN12364

McCracken, K.J., Preston, C.M., Butler, C., 2002. Effects of wheat variety and specific weight on dietary apparent metabolisable energy concentration and performance of broiler chicks. British Poultry Science, 43, 253-260. DOI: https://doi.org/10.1080/00071660120121472

McDonald, P., Edwards, R., Greenhalgh, J.F.D. (1994) Animal Nutrition. 4th ed. Longman Scientific & Technical, Harlow.

McNab, J. (1991) Factors affecting the nutritive value of wheat for poultry. HGCA Project Report No. 43 Home-Grown Cereals Authority, London, UK

Nguyen, H.T., Bedford, M.R., Morgan, N.K. (2021) Importance of considering non-starch polysaccharide content of poultry diets. World's Poultry Science Journal, 77 (3), 619-637.

Ørskov, E.R., McDonald, I. (1979) The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. The Journal of Agricultural Science, 92 (2), 499-503. DOI: https://doi.org/10.1017/S0021859600063048

Peddie, J., Dewar, W.A., Gilbert, A.B., Waddington, D. (1982) The use of titanium dioxide for determining apparent digestibility in mature domestic fowls (*Gallus domesticus*). The Journal of Agricultural Science, 99, 233-236. DOI: https://doi.org/10.1017/S002185960005526X

Percie du Sert, N., Hurst, V., Ahluwalia, A., Alam, S., Avey, M.T., Baker, M., Browne, W.J. et al. (2020) The ARRIVE Guidelines 2.0: Updated guidelines for reporting animal research. PLOS Biology 18 (7), e3000411. DOI: https://doi.org/10.1371/journal.pbio.3000411

Pirgozliev, V.R., Birch, C.L., Rose, S.P., Kettlewell, P.S., Bedford, M.R (2003) Chemical composition and the nutritive quality of different wheat cultivars for broiler chickens. British Poultry Science 44, 464-475. DOI: https://doi.org/10.1080/0007166031000085594

Pirgozliev, V.R., Rose, S.P., Kettlewell, P.S. (2006) Effect of ambient storage of wheat samples on their nutritive value for chickens. British Poultry Science, 47 (3), 342-349. DOI: https://doi.org/10.1080/00071660600741750

Pirgozliev, V., Rose, S.P., Pellny, T., Amerah, A.M., Wickramasinghe, M., Ulker, M., Rakszegi, M., Bedo, Z., Shewry, P.R. and Lovegrove, A. (2015) Energy utilization and growth performance of chickens fed novel wheat inbred lines selected for different pentosan levels with and without xylanase supplementation. Poultry Science, 94 (2), 232-239. DOI: https://doi.org/10.3382/ps/peu059

Pirgozliev, V.R., Mirza, M.W., Rose, S.P. (2016) Does the effect of pelleting depend on the wheat sample when fed to chickens? Animal, 10, 571-577. DOI: https://doi.org/10.1017/S1751731115002311

Pirgozliev, V.R., Mansbridge, S.C., Whiting, I.M., Abdulla, J.M., Rose, S.P., Kljak, K., Johnson, A., Drijfhout, F., Atanasov, A.G. (2023) The benefits of exogenous xylanase in wheat–soy based broiler chicken diets, consisting of different soluble non-starch polysaccharides content. Poultry 2, 123-133. DOI: https://doi.org/10.3390/poultry2020012

Poutanen, K.S., Kårlund, A.O., Gómez-Gallego, C., Johansson, D.P., Scheers, N.M., Marklinder, I.M., Eriksen, A.K., Silventoinen, P.C., Nordlund, E., Sozer, N., Hanhineva, K.J., Kolehmainen, M., Landberg, R. (2022) Grains – a major source of sustainable protein for health. Nutrition Reviews, 80, 1648-1663. DOI: https://doi.org/10.1093/nutrit/nuab084

Ravindran, V., Amerah, A.M. (2009) Wheat: composition and feeding value for poultry. Soybean and Wheat Crops: Growth, Fertilization and Yield. Nova Science Publishers, United States, pp. 245-259.

Refstie, S., Svihus, B., Shearer, K.D., Storebakken, T. (1999) Nutrient digestibility in Atlantic salmon and broiler chickens related to viscosity and non-starch polysaccharide content in different soyabean products. Animal Feed Science and Technology, 79, 331–345. DOI: https://doi.org/10.1016/S0377-8401(99)00026-7

Rose, S.P., Tucker, L.A., Kettlewell, P.S., Collier, J.D.A. (2001) Rapid tests of wheat nutritive value for growing chickens. Journal of Cereal Science, 34, 181-190. DOI: https://doi.org/10.1006/jcrs.2001.0390

Selle, P.H., Liu, S.Y. (2019) The Relevance of Starch and Protein Digestive Dynamics in Poultry. Journal of Applied Poultry Research, 28, 531-545. DOI: https://doi.org/10.3382/japr/pfy026

Selle, P.H., Moss, A.F., Khoddami, A., Chrystal, P.V., Liu, S.Y. (2021) Starch digestion rates in multiple samples of commonly used feed grains in diets for broiler chickens. Animal Nutrition, 7, 450-459. DOI: https://doi.org/10.1016/j.aninu.2020.12.006

Steenfeldt, S. (2001) The dietary effect of different wheat cultivars for broiler chickens. British Poultry Science, 42, 595-609. DOI: https://doi.org/10.1080/00071660120088416

Svihus, B. (2011) Limitations to wheat starch digestion in growing broiler chickens: a brief review. Animal Production and Science, 51, 583-589. DOI: https://doi.org/10.1071/AN10271

Svihus, B., 2014. Starch digestion capacity of poultry. Poultry Science, 93, 2394-2399. DOI: https://doi.org/10.3382/ps.201403905

Svihus, B., Gullord, M. (2002) Effect of chemical content and physical characteristics on nutritional value of wheat, barley and oats for poultry. Animal Feed Science and Technology, 102, 71-92. DOI: https://doi.org/10.1016/S0377-8401(02)00254-7

Yang, Z., Pirgozliev, V.R., Rose, S.P., Woods, S., Yang, H.M., Wang, Z.Y., Bedford, M.R. (2020) Effect of age on the relationship between metabolizable energy and digestible energy for broiler chickens. Poultry Science, 99 (1), 320-330. DOI: https://doi.org/10.3382/ps/pez495

Weurding, R.E., Veldman, A., Veen, W.A., van der Aar, P.J., Verstegen, M.W. (2001) Starch digestion rate in the small intestine of broiler chickens differs among feedstuffs. The Journal of Nutrition, 131 (9), 2329-2335. DOI: https://doi.org/10.1093/jn/131.9.2329

Whiting, I.M., Pirgozliev, V., Bedford, M.R. (2023) The effect of different wheat varieties and exogenous xylanase on bird performance and utilization of energy and nutrients. Poultry Science, 102, 102817. DOI: https://doi.org/10.1016/j.psj.2023.102817

Wiseman, J., Nicol, N.T., Norton, G. (2000) Relationship between apparent metabolisable (AME) values and in vivo/in vitro starch digestibility of wheat for broilers. World's Poultry Science Journal, 56, 305–318. DOI: https://doi.org/10.1079/WPS20000022