Evaluation of oats with varying hull inclusion in broiler diets up to 35 days

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ABSTRACT

Use of local feed ingredients in poultry feed, such as oats, can be limited by their perceived less than ideal nutritional content. Dehulling oats is expensive and it may be that removing hull is detrimental to the bird in terms of gastrointestinal (GI) development, therefore maintaining some of the high fiber oat hull might reduce costs and improve potential for inclusion in poultry diets.

Male broilers were fed diets with oats replacing 30% of wheat in diets, either dehulled or with graded inclusions of oat hull from day of hatch until day 35. Each diet was fed to 8 pens of 8 birds and performance recorded weekly. Samples were collected at day 21 and 35, for analysis of ileal amino acid digestibility, apparent metabolizable energy (AME) and gross gut development measures.

No detrimental effect was seen on bird weight with hull inclusion, though higher inclusion levels did deleteriously effect feed intake due to increased gut fill from the fiber. AMEn was also adversely effected in the highest hull inclusion diets. However, amino acid digestibility was improved with hull addition, which may be due to an increase in GI tract length, improving nutrient absorption. Gizzard development was also significantly improved and thereby more efficient grinding of diet may also have improved digestibility. At a lower level of hull inclusion (3% total diet) where digestibility is improved without any detrimental effects on gut fill and intake.

Oat hull is well known to improve gut development, especially of the gizzard, with resultant increases in digestibility. This is usually attributed to the mechanical effect of fiber in the gizzard having a grinding effect. However in this study, all fiber was finely ground, so the improvements seen cannot be attributed to a physical cause. Oat including diets with some hull remaining are a cost effective way of utilizing oats as a raw material while maximizing bird performance.

Keywords: broiler, oats, fiber, nutrition

INTRODUCTION

Increasing global protein supply is essential for the growing population and the poultry sector has expanded rapidly to fulfil this requirement. This rapid growth in production has increased interest in the use of alternative and local feed ingredients combined with the reduction of waste. Oats are not widely fed to broilers, where weight gain is of primary importance, due to their high fibre content (around 10%) and low energy when compared to wheat or maize. This fibre is due to the oat hull, which makes up an average of 27% of the total weight of the oat (McDonald et al., 2002). Hull content can vary between varieties and growing conditions but is always high in insoluble fibre, up to an estimated 95% (Lopez-Guisa et al., 1988). The oat fibre includes non-starch polysaccharides (30-35%) and lignin (10-15%), the latter being virtually indigestible and is present in oats in double the amount seen in other cereals (Thacker et al., 2009). Oats also have a low concentration of prolamins compared to wheat, which increases protein quality, particularly available lysine and results in an excellent amino acid balance (Robbins et al., 1971). Oats are high in lysine, methionine and cysteine compared with other cereals which is a consideration with the increase in vegetable based diets where these essential amino acids are regularly supplemented. Oats are typically less expensive than wheat, with UK prices standing around £110/t for oats compared with £140/t for wheat (AHDB, 2019).

Highly digestible diets are commonly fed in the early starter period to broilers to support early growth as this can be linked to final bodyweight at slaughter (Noy and Sklan, 1999). Chicks have poorly developed gastrointestinal tracts at hatch and therefore these early diets tend to support nutrient retention by using readily digestible ingredients and therefore tend to be low in insoluble fibre, as this can be considered a nutrient diluent. However, dietary fibre may increase retention time in the upper gastrointestinal tract (GIT) and improve gizzard function (Hetland, 2005) while also stimulating HCl production in the proventriculus (Duke, 1986). This leads in turn to a lower pH in the gizzard which increases pepsin activity and mineral absorbance (Guinotte et al., 1995). It is well established that dietary fibre can have a positive effect on gizzard development and nutrient digestibility (Mateos, 2002), and therefore there is increasing interest in the addition of fibre to poultry diets, both as a cost reduction measure, and to enhance gizzard function.

Oat hulls are a source of insoluble fibre which is high in lignin content and resistant to grinding which results in stimulation of gizzard activity and an improvement in the development of the muscular layers of the gizzard thereby increasing gizzard size (Rogel at al., 1987; Gonzalez Alvarado et al., 2008). Oat hulls may also decrease pH in the gizzard supporting enzyme activity (Gonzalez Alvarado et al., 2008) and the retention of coarse particles in the gizzard may cause reflux of digesta from later in the GIT back to the gizzard thereby improving nutrient utilisation (Rogel et al., 1987). Wallis et al. (1985) concluded that feed intake was increased by supplementing the wheat based diet with 10% oat hull. Jiménez-Moreno et al. (2009) found that inclusion of 3% of either oat hull or sugar beet pulp improved weight gain from 1 to 21 days old, and the same research group also found that body weight gain (BWG) and feed conversion rate (FCR) were improved with increasing oat hull inclusion in younger broilers (Jimenez-Moreno et al., 2010). In other types of poultry such as laying hens, oats may have additional positive effects on behaviours such as feather pecking (Kjaer and Bessei, 2013)

Naked oats have a specific phenotype which means they have no hull post harvesting (Ougham et al, 1996). Naked oats can be fed with or without enzymes at high inclusion levels. Historically they have been incorporated at levels up to 60% in starter diets (Hulan et al, 1981). Cave and Burrows (1985) fed up to 30% naked oats to broilers with similar performance to a corn-wheat-soy control diet, but found that increasing inclusion to 60% naked oats decreased feed efficiency. However, naked oats are not widely utilised in broiler diets due to increased cost, as the yield from these varieties tends to be poorer and therefore there is a cost implication. Oats can be dehulled after harvesting, but this is a time consuming and therefore also an expensive process which reduces the use of dehulled oats, and can leave a considerable amount of hull which needs to be utilised elsewhere. It may be that a product with less hull removed would bring benefits to nutrient digestibility in the bird while reducing processing costs.

The aim of this study was to quantify the effect of varying oat hull inclusion levels in broiler diets containing dehulled oats, on bird performance measures, ileal apparent amino acid digestibility, digestibility of AMEn and gross gut development measures. The objective of this study was to determine whether addition of oat hull back into dehulled diets may be an economic option for inclusion in broiler diets.

MATERIALS AND METHODS

Birds and Husbandry

Male, Ross 308 broilers (n = 320) from a 51-week-old breeder flock were obtained from a commercial hatchery at day of hatch. Chicks were randomized by weight and placed in 0.64 m^2 floor pens in groups of 8, bedded on clean wood shavings. 40 pens of eight birds were fed one of five dietary treatments, with 8 replicate pens per treatment. Birds were allowed ad libitum access to the treatment diets and water for the duration of the trial. The room was thermostatically controlled to produce an initial temperature of 32°C on d1 and reduced in steps of 0·5°C per d, reaching 21°C by day 14. The lighting regimen used was 24 hours light on d1, with darkness increasing by 1 hour a day until 6 hours of darkness was reached, which was maintained throughout the remainder of the study as required by EU legislation (EU Council Directive 2007/43/EC). All birds sampled were euthanized by cervical dislocation. This occurred at the same time each sampling day; after at least 4 hours of light, to ensure maximal gut fill. Institutional and UK national NC3R ARRIVE guidelines for the care, use and reporting of animals in research (Kilkenny et al., 2010) were followed and all experimental procedures involving animals were approved by the Nottingham Trent University's College of Science and Technology ethical review committee.

Dietary Treatments

Diets were formulated in two phases; Starter (d0-21) and Finisher (d21-35), with diet formulations for each phase shown in Table 1.

The dietary treatments were created by replacing 30% of the wheat in the control diet with dehulled oats mixed with oat hull (OH) prior to manufacturing the diets. The dehulled oat was assumed to contain 3% hull, so to produce 3, 10, 20 and 30% total hull content in the oats, the hull was mixed at 0, 7, 17 and 27%, so that the final diets containing, 0.9, 3, 6 and 9% OH. The oat variety used was the winter oat Mascani, with dehulled oats (groats) containing 12.9% protein, 4.6% fat and 2.8% fiber (9% NDF, 3% ADF), whereas the oat hulls used contained 5.1% protein, 1.2% fat and 27.9% fiber (59% NDF, 32% ADF).

Diets were fed in mash form, mixed in house, and were analyzed for gross energy by bomb calorimetry (Robbins and Firman, 2006), dry matter, extractable fat and protein content (calculated as nitrogen multiplied by 6.25) by the AOAC standard methods (930.15, 2003.05 and 990.03, respectively). Phosphorus and Ca content of the diets were analyzed by inductively coupled plasma-optical emission spectroscopy (ICP-OES) following an aqua regia digestion step (AOAC 985.01). Titanium dioxide was added at a rate of 5g/kg to act as an inert marker for evaluation of digestibility and the dietary titanium dioxide content quantified by the method of Short et al. (1996). Crude fiber and NDF and ADF fiber fractions were analysed as described by Van Soest et al. (1991). Analysed nutritional content of the diets including amino acid contents are reported in table 2.

Response Variables

On arrival birds were individually weighed and allocated to a pen. Pen allocation was randomized across the room. Total pen weight and mean chick body weight (BW) were calculated, and diet allocation was arranged to ensure there was no significant difference in BW by pen across diets. Total pen weight and feed intake (FI) were determined weekly until 35 days post-hatch and was used to calculate feed conversion ratio (FCR). The pen weight and intake was divided by the number of birds in the pen to determine individual bird BW and FI. Mortality was recorded daily, and any birds culled or dead were weighed. FCR was corrected for mortality.

Four birds per pen were euthanized on both d21 and d35, and ileal digesta collection collected from three birds by gentle digital pressure and pooled into one pot per pen. The gastrointestinal tract was removed from the remaining bird in each pen on both d21 and d35 and length and weight of jejunum, ileum, duodenum and gizzard recorded after flushing with distilled water. On d21, digesta was also collected from the jejunum of the 3 birds per pen and pooled for measurement of digesta supernatant viscosity, using a Brookfield cone and plate viscometer, maintained at 41^{o}C to mimic chick body temperature. At d35, excreta was collected from each pen by manually picking a minimum of 10g of fresh excreta, ensuring bedding contamination was kept to a minimum and samples dried at 80^{o}C for 5 days before grinding to pass through a 1mm screen. Ileal samples were freeze dried and finely ground with a pestle and mortar. The ground digesta and excreta samples were analyzed for titanium dioxide content by the method of Short et al. (1996), for gross energy by bomb calorimetry (Robbins and Firman, 2006) and for nitrogen content by the AOAC method as detailed previously. Amino acid content of diets and digesta were analysed using a Biochrom 30 amino acid analyser based on ion exchange chromatography. Samples were prepared for analysis by oxidation with performic acid prior to acid hydrolysis with 6N HCl with Norleucine added as an internal standard. Amino acid standards were prepared containing 200nmol/ml of amino acids and norleucine and these were used to calculate amino acid content of the digesta and diets after internal standard correction was applied. Apparent amino acid digestibility was calculated using the following equation:

$1-(aa_{dig} * marker_{feed}) / (aa_{feed} * marker_{dig})$

Where

aa_{dig} represents the amino acid content of the digesta

$marker_{feed}$ represents the titanium concentration in the diet

aa_{feed} represents the amino acid concentration in the diet

$marker_{dig}$ represents the titanium dioxide concentration in the digesta

The determined apparent digestible amino acid content of the diets was then divided by the total content of the specific amino acid in the diet gave a coefficient of apparent amino acid digestibility, for each amino acid per dietary treatment.

Data Analysis

All data were analyzed using SPSS v23 (IBM Statistics). After Kolmogorov–Smirnov testing to confirm normality, data were analysed using one-way ANOVA to test the equality of the means to investigate the effect of dietary treatment on performance, digestibility of AMEn, apparent ileal amino acid digestibility, gross gut measures and digesta viscosity. Duncan post hoc tests were used to elucidate differences between diets. Correlations between digestiblity measures and oat hull content were analysed by bivariate correlation using Pearson product-moment correlation coefficient with strength of relationships based on guidelines by Cohen, (1988); weak relationship r = 0.10 to 0.29, medium relationship r = 0.30 to 0.49 and strong relationship r = 0.50 to 1.0. Statistical significance was declared at $p<0.05$.

RESULTS AND DISCUSSION

The performance of the birds from d0 to 35 is shown in table 3. Bodyweight gain and feed intake were not significantly altered, though the highest bodyweight at d35 was in the dehulled oat and the 27% OH, with the latter also having the highest feed intake numerically. This increase in feed intake resulted in a poorer FCR for the 17 and 27% OH diets when compared with the dehulled oat diet ($p = 0.041$). It appears that the birds can maintain their bodyweight on high levels of hull inclusion, but this is by increasing their intake of feed, mitigating any cost benefit from including this level of OH. However, wheat maintains a price point of around 20% higher than oats, so a 7% increase in feed costs may still provide a financial incentive in such a low margin industry. Other authors have reported an increase in feed intake with 10% OH supplementation (Wallis et al., 1985) and with 4% OH (Hetland and Svihus, 2001) with both these studies also not showing any bodyweight improvement over the control diets. Oat hull has high insoluble fibre and lignin so therefore the rate of passage of digesta may be increased, leading to increased feed intake (González-Alverado et al., 2010) as seen in the higher hull diets in this study. The authors hypothesized that the higher lignin and cellulose content combined with an increased level of insoluble fibre resulted in a higher rate of ingesta passage through the distal part of the digestive tract which leads to increased feed intake, while also minimising enzyme digestion, due to limited access of digesta to the mucosa. Some authors have argued that higher inclusion levels (up to 16% fibre) can reduce feed intake and therefore bodyweight due to the limited digestive tract of broilers combined with the increased diet bulk (Khempaka et al., 2009), so higher levels of fibre may be detrimental and should be avoided.

Hetland and Svihus (2001) also observed that an inclusion of up to 10% OH did not affect BW unduly due to the increased digesta transit time, which allowed for increased FI. Jiménez-Moreno et al. (2009) found that low inclusion (3%) of OH improved weight gain in young broilers and in a later study, the same authors found that both BWG and FCR were improved with increasing OH inclusion also in younger broilers (Jimenez-Moreno et al., 2010) which contrasts with our findings. Although FCR was not detrimentally affected up to 7% OH inclusion, the FCR was poorer in the higher hull diets, which may be due to the higher levels utilised in this study, or the younger birds used by the other authors. In the current study, both the oats and hulls were finely ground, which may also reduce negative effects, as it has been reported that coarsely ground OH impaired FCR in young broilers more than finely ground (Hetland and Svihus, 2001)

Performance for the dehulled oat diet was comparable to the wheat based control diet, which is comparable with previous studies which showed that up to 30% naked oats did not adversely affect performance (Cave and Burrows, 1985), although the same study did show that increasing inclusion to 60% did depress feed efficiency, so maximum levels need to be carefully considered when incorporating even dehulled oats into broiler diets. The higher fat content of the oat containing diets may also have an effect on pellet quality, which needs to be studied further in subsequent work. In this study, the viscosity of the digesta supernatant was low and not significantly different across diets (see Table 4). Wheat containing diets normally increase digesta viscosity so, as oats contain less soluble fibre than wheat, and oat hulls are made up of mainly insoluble fibre, it would be unlikely that addition of oats would have altered the measures. It is therefore unlikely in this study that digestibility or other measures were due to changes in viscosity.

The effect of OH inclusion on Apparent metabilizable energy (AME) and nitrogen corrected AME (AMEn) is shown in table 4. AME was reduced significantly in the 27% OH diet when compared with the dehulled oat and AMEn was similarly effected. Oat hull content was negatively correlated to both AME (r=-0.556, p=0.001) and AMEn (r=-0.563, p=0.001), but there did not appear to be a relationship to nitrogen digestbility. OH fibre can be considered a diluent of energy and nitrogen and so it might be expected that digestibility would reduce with fibre inclusion, however, other authors have previously shown increases in AMEn with fibre inclusion (Jimenez Moreno et al., 2009, 2010). It may be that the increase in AMEn seen by other authors is due in part to improved fat retention, lipids may adhere to hulls and therefore benefit emulsification of fats, while reducing the excretion of bile acids as they bind poorly to the bile salts in the intestine (Mueller et al., 1983). In this study, the included fat levels (4-5%) may have been too low to have any substantial effect on energy digestibility.

Total length and weight of the small intestine of the birds fed diets with graded OH levels are shown in table 5 for d21 and d35. There were no significant differences recorded between diets at d21 across weight or length individually for the duodenum, jejunum, ileum or gizzard (data not shown), but the overall small intestine length was improved in birds fed the 27% OH diet compared with the diets with dehulled oats with or with 7% OH. This difference was not maintained until d35, although the highest hull diet did still have the numerically heaviest and longest small intestine compared with the other diets. The effect of dietary fibre inclusion on GIT length and weight shows a lack of consensus in the literature, with some authors suggesting an increase with fibre inclusion (Khempaka et al., 2009) and that the physical capacity of the GIT may be improved with fibre inclusion, thereby allowing for increased FI, as recorded in this study. However, oat hulls do not have a high water holding capacity and therefore do not tend produce a bulky digesta (Bach Knudsen 2001). Other authors report a decrease in small intestinal length and weight when 10% OH were included (Rogel et al., 1987), potentially due to an increase in gizzard size leading to a comparatively reduced small intestine (Taylor and Jones, 2004).

Gizzard size was significantly improved in birds fed the highest hull diets compared with the birds fed other diets at d35 (Table 4). Enlarged gizzards may retain feed and thereby increase contact time for digestive enzymes with associated improvements in digestion (Jones and Taylor 2001), and increased muscular development will increase grinding ability, with subsequent improvements in nutrient digestibility. No significant effect was seen on gizzards on the lower hull diets, though a small numerical difference seen may be relevant considering that gizzard contents have been reported to increase with feeding of insoluble fibre, even when gizzard size is unaffected (Svihus, 2011). This may suggest an increase in structural size without a substantial weight increase, and therefore improved holding capacity, though this would need to be confirmed in further studies. Gut motility and digesta movement within the tract may also be improved, as larger particles can induce peristalsis, with a subsequent increase in nutrient digestibility (Mateos et al. 2002). Although the OH fed were all ground in this study, previous studies have shown that when oats were ground through a 0.5mm screen and a 2mm screen they were shown to have a very similar geometric mean diameter (only reduced slightly when more finely ground), suggesting that even finely ground oats maintain some of their physical structure (Jimenez-Moreno et al, 2010). Therefore grinding of OH does not appear to deleteriously effect gizzard retention or pH, unlike with other fibre sources such as sugar beet pulp.

Effect of OH inclusion on apparent ileal amino acid digestiblity at d35 is shown in Table 6. The amino acid digestiblity across diets showed the same pattern for d21 (data not shown). The average coefficient of digestibility for the dehulled oat diet was 0.82 reducing to 0.80 for 27% OH diet, and again to 0.75 for the 17% OH diet. Perttila et al. (2008), reported a COD of

0.79 for oats compared with 0.86 for wheat, with higher digestibility for dehulled oats compared with whole oat, particularly for cystine. In this study, the wheat diet COD did not substantially differ from either the dehulled oat, or the highest OH inclusion diet, although amino acid digestibility was depressed for the lower OH diets. Interestingly cysteine, lysine and methionine digestibilities were no different between the 27% OH diet and the dehulled oat diet. This may be due in part to improved availability of amino acids released by the increased grinding capacity of the gizzard (Jiménez-Moreno et al., 2009). Hetland et al. (2003) also found increased bile acids in the gizzard in birds fed diets containing OH, suggesting that the nutrients may be more solubilised by an increase in GI reflux. The birds may also have lower pH in the proximal gastrointestinal tract, due to increased HCl excretion from the proventriculus, which may improve pepsin activity and thereby increase utilisation of protein and hence amino acid utilization (Gabriel et al., 2003). This lower pH may also influence pathogenic bacteria in the latter digestive tract leading to increased SCFA produced and stimulation of the growth of beneficial bacteria (Enberg et al., 2004).

This study shows that high hull oat diets (equivalent to unhulled oats) can be fed to birds with no detrimental effect on bird weight, but with increased feed intake and reduced AMEn, which may reduce economic advantages from feeding whole oat diets. However, amino acid digestibility was improved with high OH diets, to the equivalent of dehulled oats, which may be explained in part by the concurrent increase in gastrointestinal length and gizzard weight recorded. Future studies would benefit from examining the gut microflora and pH in similar diets to elucidate the mechanisms for these effects. Locally grown oats may be utilised in diets without or with minimal expensive dehulling and thereby improve the security of production of broiler meat.

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Table 1. Formulated composition of Wheat control diet (g/kg)

Raw Material	Starter (g/kg)	Finisher (g/kg)
Wheat	625.4	713.8
HiPro Soya (48.5% CP)	300.0	206.0
Limestone	8.0	7.2
Dicalcium phosphate (18%)	13.1	11.1
Salt	1.6	1.8
Sodium bicarbonate	2.5	1.5
Vit/Min premix*	3.5	3.5
Lysine HCl	3.6	2.8
DL Methionine	3.9	2.3
L Threonine	1.4	1.0
Soya oil	32.0	44.0
Titanium dioxide	5	5

*Premix content (volume/kg diet): Mn 100mg, Zn 88mg, Fe 20mg, Cu 10mg, I 1mg, Mb 0.48mg, Se 0.2mg, Retinol 13.5mg,Cholecalciferol, 3mg, Tocopherol 25mg, Menadione 5.0mg, Thiamine 3mg, Riboflavin 10.0mg, Pantothenic acid 15mg, Pyroxidine 3.0mg, Niacin 60mg, Cobalamin 30µg, Folic acid 1.5mg, Biotin 125mg.

419 **Table 2.** Analyzed content of experimental diets

	Control (no oat)	30% dehulled oat	30% oat with 7% hull	30% oat with 17% hull	30% oat with 27% hull
Starter					
GE Content (MJ/kg)*	16.42	17.00	17.09	17.27	16.81
Protein Content** (g/kg)	233	227	212	213	216
Fat (g/kg)	37.5	46.0	45.8	43.6	43.1
Phosphorus (g/kg)	5.49	6.69	6.05	5.39	5.04
Calcium (g/kg)	8.48	10.11	9.75	8.43	7.92
Crude Fiber (g/kg)	37.7	37.5	41.5	53.8	60.6
NDF (% of fiber)	16.1	9.6	9.9	12.1	13.2
ADF (% of fiber)	3.4	3.7	3.8	4.9	5.5
Finisher					
GE Content (MJ/kg)	16.90	17.33	17.15	17.33	17.53
Protein Content (g/kg)	198	193	186	196	187
Fat (g/kg)	46.0	53.3	52.6	49.4	53.2
Phosphorus (g/kg)	4.96	5.21	4.89	5.13	5.24
Calcium (g/kg)	7.54	7.61	6.73	7.58	8.37
Crude Fiber (g/kg)	30.6	29.8	35.7	45.5	56.5
NDF (% of fiber)	12	9.7	10.9	11.8	13.8
ADF (% of fiber)	2.6	4.4	6.3	4.9	5.8
Amino acids (g/kg)					
Cysteine	7.219	6.492	5.824	5.891	6.407

Aspartic acid	15.996	14.402	16.15	14.028	16.098
Threonine	6.89	9.043	6.802	5.499	6.867
Serine	8.834	10.726	8.546	7.779	8.452
Glutamate	40.936	45.366	36.53	39.521	35.982
Glycine	7.187	10.09	7.865	6.797	7.376
Alanine	6.186	9.155	7.203	6.454	6.701
Methionine	7.787	9.239	8.548	6.388	8.634
Isoleucine	5.563	5.329	4.965	2.517	4.701
Leucine	7.171	8.303	7.31	5.366	7.267
Tyrosine	12.869	15.149	12.83	11.709	12.573
Phenylalanine	4.309	5.145	4.933	2.669	4.452
Lysine	8.864	9.831	8.649	7.87	8.39
Histidine	11.241	13.256	12.359	7.039	11.175
Arginine	4.008	4.825	4.016	3.843	3.837

*Gross energy measured by bomb calorimetry

**Protein calculated by Nitrogen (via Dumas)* 6.25

Table 3. Effect of oat inclusion on growth performance of broilers from d 0 to 21 and d0 to 35 (Feed intake, Bodyweight gain (BW) and feed conversion ratio (FCR)

Diet	FI d0-21	BWG d0-21	FCR d0-21	Fi d0-35	BWG d0-35	FCR d0-35
Control (no oat)	1127	850	1.33^{ab}	3412	2278	1.50^{ab}
30% dehulled oat	1124	850	1.32^{ab}	3453	2332	1.48^{a}
30% oat with 7% hull	1153	885	1.31^{a}	3454	2314	1.49^{ab}
30% oat with 17% hull	1078	745	1.46^{c}	3384	2164	1.57^{b}
30% oat with 27% hull	1173	822	1.44^{bc}	3665	2343	1.56^{b}
SEM	30.4	33.4	0.042	74.3	52.1	0.024
P-value	0.327	0.063	0.033	0.194	0.178	0.041

$^{a–b}$ Means within the same column with no common superscript differ significantly ($P \leq 0.05$).

1-way ANOVA and Duncan Post-Hoc test were used to differentiate between means.

SEM is standard error of the mean

Table 4. Influence of oat hull inclusion on AME, AMEn (apparent metabolisable energy, and nitrogen corrected AME) and gizzard weight at d35(g)

Diet	AME (MJ/kg)	AMEn (MJ/kg)	Viscosity (cP)
Control -no oat	13.04^{ab}	12.38^{a}	2.04
30% dehulled oat	13.68^{a}	13.02^{a}	1.85
30% oat, 7% hull	13.23^{ab}	12.55^{a}	2.50
30% oat, 17% hull	12.10^{ab}	11.46^{ab}	2.37
30% oat, 27% hull	11.14^{b}	10.50^{b}	2.07
SEM	0.56	0.55	0.18
P-value	0.022	0.019	0.182

$^{a–c}$ Means within the same column with no common superscript differ significantly ($P \leq 0.05$).

1-way ANOVA and Duncan Post-Hoc test were used to differentiate between means.

Table 5. Length and weight of the small intestine (SI)[1] in birds fed differing levels of oat hull inclusion at d21 and d35

Diet	SI length d21 (mm)	SI weight d21 (g)	SI length d35 (mm)	SI weight d35 (g)	Gizzard weight (g)
Control -no oat	1636^{ab}	42.4	1959	66.5	26.1^{b}
30% dehulled oat	1559^{b}	39.7	1980	72.1	27.0^{b}
30% oat, 7% hull	1515^{b}	36.1	2001	71	28.2^{b}
30% oat, 17% hull	1607^{ab}	38.1	2011	68.1	28.6^{b}
30% oat, 27% hull	1722^{a}	40.6	2079	77.6	32.9^{a}
SEM	44.4	1.82	62.7	3.6	1.06
P-value	0.031	0.291	0.734	0.292	0.005

[1] Small intestine is defined as the portion between the beginning of the duodenal loop and the ileal-cecal-colonic junction.

$^{a–c}$ Means within the same column with no common superscript differ significantly ($P \leq 0.05$). 1-way ANOVA and Duncan Post-Hoc test were used to differentiate between means.

Table 6. Amino acid digestibility of diets containing oats with incremental hull content

	Control	30% dehulled oat	30% oat 7% hull	30% oat 17% hull	30% oat 27% hull	SEM	*P-Value*
Cystine	0.830^{a}	0.737^{b}	0.659^{c}	0.713^{b}	0.739^{b}	0.016	<0.001
Aspartic Acid	0.784^{a}	0.742^{ab}	0.738^{ab}	0.726^{b}	0.783^{a}	0.016	0.05
Methionine	0.913^{a}	0.901^{a}	0.870^{b}	0.795^{c}	0.896^{ab}	0.010	<0.001
Threonine	0.771^{ab}	0.816^{a}	0.718^{bc}	0.696^{c}	0.770^{ab}	0.017	<0.001
Serine	0.812^{a}	0.823^{a}	0.747^{b}	0.755^{b}	0.783^{ab}	0.014	0.002
Glutamine	0.884^{a}	0.882^{a}	0.828^{b}	0.869^{a}	0.874^{a}	0.009	<0.001
Glycine	0.744^{ab}	0.794^{a}	0.692^{b}	0.692^{b}	0.740^{ab}	0.017	0.001
Alanine	0.725^{b}	0.801^{a}	0.706^{b}	0.711^{b}	0.754^{ab}	0.018	0.005
Valine	0.741^{ab}	0.773^{a}	0.718^{bc}	0.673^{c}	0.771^{a}	0.017	0.002
Isoleucine	0.801^{a}	0.815^{a}	0.751^{b}	0.709^{b}	0.803^{a}	0.015	<0.001
Leucine	0.816^{ab}	0.834^{a}	0.764^{c}	0.785^{bc}	0.820^{ab}	0.013	0.004
Tyrosine	0.806^{a}	0.817^{a}	0.764^{a}	0.634^{b}	0.798^{a}	0.020	<0.001
Phenylalanine	0.810^{abc}	0.829^{a}	0.773^{c}	0.787^{bc}	0.825^{ab}	0.012	0.014
Lysine	0.846^{a}	0.865^{a}	0.827^{a}	0.727^{b}	0.850^{a}	0.015	<0.001
Histidine	0.800^{ab}	0.835^{a}	0.765^{b}	0.779^{b}	0.803^{ab}	0.013	0.012
Arginine	0.860^{abc}	0.889^{ab}	0.846^{c}	0.853^{bc}	0.893^{a}	0.012	0.037
Proline	0.852	0.848	0.820	0.840	0.824	0.010	0.154

$^{a\text{–}c}$ Means within the same row with no common superscript differ significantly ($P \leq 0.05$). 2-way ANOVA and Duncan Post-Hoc test were used to differentiate between means.