The effect of moderate levels of finely ground insoluble fibre on small intestine morphology, nutrient digestibility and performance of broiler chickens

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ABSTRACT
This experiment was carried out to assess the following hypothesis: feeding broiler to fine insoluble fibre in the diet will result in improved gut morphology and enhanced performance. In this experiment, 200 broiler chickens in 20 pen cages with wood shaving-lined floors were exposed to five treatment groups with four pens/treatment: control diet, diets contained 0.75 or 1.5% barley hulls or diets contained 0.75 or 1.5% rice hulls in a completely randomised design with five treatment, four replicate and 20 chicks each. Type of fibre influenced the performance and digestive traits of broilers with effects varying in accordance with the level of fibre. Rice hulls inclusion consistently improved growth performance and crude protein (CP) digestibility in broilers regardless of dietary inclusion level ($p < 0.05$). However, barley hulls at 1.5% level improved crypt depth: villous height (VH) ratio and feed conversion ratio had an opposite effect on VH ($p < 0.05$). The beneficial effects of hulls were more obvious with the 1.5% dietary inclusion level than the 0.75% level. The useful effects of rice hulls inclusion on broiler efficiency was mainly because of its effect on CP digestibility while barley hulls at 1.5% level positively changed jejunum morphology. The data suggest that broilers may have a nominal requirement for insoluble fibre, however, the source and dietary inclusion rate of fibre might be important factors to satisfy dietary fibre requirements in birds.

Introduction

In commercial poultry diet formulation, dietary fibre is usually considered as energy diluent and as an antinutritional factor which negatively affect feed consumption and nutrient digestibility (Rougière & Carré 2010; Navidshad et al. 2015). On the other hand, there are some reports on the favourable effects of moderate dosage of insoluble fibre in the diet. The inclusion of dietary fibre may improve HCl (Jiménez-Moreno et al. 2010) and bile acids and enzyme secretion (Hetland et al. 2003) and better gizzard function (Hetland et al. 2005) which improve nutrient digestibility and performance traits of broilers (Jiménez-Moreno et al. 2009a,b; González-Alvarado et al. 2010). Such benefits have been observed when certain levels of insoluble fibre such as oat hulls, pea hulls or wood shavings were added to the diet (Hetland et al. 2003; Amerah et al. 2009; Jiménez-Moreno et al. 2011). The effects of dietary fibre depend on the dosage of inclusion, particle size and the physicochemical characteristics of the fibre source (Schneeman 2001; Amerah et al. 2009). Grinding of dietary fibre might affect its physical characteristic. A finely ground fibre may damage gizzard function, decreasing nutrient digestibility and broiler performance.

The precise mechanisms of gastrointestinal tract (GIT) alteration to dietary fibres are not obviously understood yet and insufficient scientific report exists on the effects of the small particle size of fibre on the development of the GIT of broilers. We hypothesise that finely ground dietary fibre might have some useful effects on the nutrient digestibility and performance traits of broilers. The aim of this experiment was to evaluate the effect of inclusion of 0.75 or 1.5% rice or barley hulls with less than 1 mm particle size, on the small intestinal morphology, nutrient digestibility and growth performance of broilers from 10 to 42 d of age.
Materials and methods

Fibre sources and diets

A batch of rice hulls, a by-product of the rice industry for human consumption, was obtained from Astara (Guilan, Iran) and a batch of barley hulls, a by-product of the barley, were obtained from Ardabil (Ardabil, Iran). The two fibre sources were ground with a hammer mill to pass through a 1-mm screen and used as the main dietary fibre sources. The metabolisable energy of hulls samples was determined by Sibbald procedure (Sibbald 1976a,b). Dry matter (DM), crude protein (CP), ether extracts and ash content of the hulls and diets were assayed according to AOAC (2000). The diets were formulated to meet the nutrient requirements of Ross 308 broilers (Aviagen 2009, AL, USA). Chromic oxide (Cr2O3) was added at 0.5% to all diets as a marker. All diets were fed in mash form. The chemical analyses of rice and barley hulls are shown in Table 1.

Total tract digestibility

At 34, 35 and 36 d of age, representative samples of excreta were collected by replicate, homogenised, dried in an oven (60°C for 72 h) and ground with a hammer mill (fitted with a 1-mm screen. Diets and excreta samples were analysed by Soxhlet fat analysis after 3 N HCl acid hydrolysis (Method 4.b) as described by Boletín Oficial del Estado ( 1995). Neutral and acid detergent fibre of fibre sources and diets were determined sequentially as described by Van Soest et al. (1991) and expressed on an ash-free basis (AOAC2000). The chromic oxide was determined according to Fenton and Fenton (1979). The apparent digestibility of nutrients was calculated by using the following formula:

Apparent digestibility of nutrients (%) = \frac{(\text{nutrients/marker})_{\text{diet}} - (\text{nutrients/marker})_{\text{excreta}}}{(\text{nutrients/marker})_{\text{diet}} \times 100}

where, nutrients/marker = \text{theratio of nutrients to Cr}_2\text{O}_3.

Husbandry and experimental design

The experiment was carried out according to the Animal Ethics Guidelines of University of Mohaghegh Ardabili, Iran. A total of 200 one-day-old chicks (Ross 308) was obtained from a commercial hatchery (Arta Joujeh, Ardabil, Iran) and allocated in an environmentally controlled house. Chicks were raised on a commercial starter diet and randomly divided among 20 pens (3 x 1.5 m) with wood shaving-lined floors at 11 d of age. The pens were equipped with a drinker cup and an open trough feeder. Four pens per treatment were assigned to each of five isocaloric and an isonitrogenous diet consisting of a control diet without an additional source of fibre or diets contained rice or barley hulls at either 0.75 or 1.5% level (Table 2). House temperature was kept at 33°C at first 3 d of rearing period and then, the temperature was reduced gradually according to the age of bird until reaching 18°C at 42 d. The broiler chickens were raised on a 23 h/d light programme. The diets were offered ad libitum and the birds had free access to water throughout the trial.

Broiler growth and digestive organ development

The body weight (BW) of broiler chickens and feed consumption were determined by pen at 11, 24 and 42 d of age for starter, grower and finisher phases, respectively, and daily BW gain (BWG), average daily feed intake (ADFI) and feed conversion ratio (FCR) were determined. The FCR was multiplied by the price of corresponding diets to calculate the feed cost per kg live weight and the calculated value demonstrated as a ratio of the control treatment. At 42 d of age, two chickens per replicate (a male and a female) were randomly selected and slaughtered. The GIT with digesta contents weighed. Empty BW (without the liver and the GIT and its contents) was determined. The gizzard and abdominal fat pad was then excised, dried with desiccant paper and weighed. The weight of the empty organs was expressed relative to live BW.

Small intestine morphology

For intestinal histology traits, the digestive tract from the gizzard to the bile duct, from the bile duct to the Meckel’s diverticulum and from Meckel’s diverticulum to the ileocaecal junction was designated duodenum, jejunum and ileum, respectively. Three 1 cm tissue segments were taken from the proximal, middle and distal

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Table 1. Chemical composition (%), unless otherwise indicated) of barley and rice hulls.

|                | Barley hulls | Rice hulls |
|----------------|-------------|------------|
| Dry matter (%) | 92          | 93         |
| Metabolisable energy, Kcal/kg | 978 | 834 |
| Ash (%)        | 3.53        | 16.79      |
| Ether extract  | 4.26        | 3.49       |
| Crude protein  | 12.26       | 3.23       |
| Crude fibre    | 12.6        | 37.5       |
| NDF            | 52.1        | 76         |
| ADF            | 23.5        | 56         |
| Lignin         | 15.5        | 26         |
| Ca (%)         | 0.9         | 0.8        |
| P (%)          | 0.6         | 0.27       |

NDF: Neutral detergent fiber; ADF: Acid detergent fiber.
parts of each segment. All samples were taken from the same part of each section of the tract. Samples stored in 10% buffered neutral formalin for fixation, where they were gently shaken to eliminate any adhering digesta. Cross sections (5 μm thick) of each intestinal section were processed in low-melt paraffin and stained with haematoxylin and eosin. This procedure causes a longitudinal section of villi. Using a Zeiss light microscope, 15 measurements per intestinal section were made for each parameter and averaged into one value per bird. Actually, each histological data obtained from the mean of 45 records (three sections and 15 villi per section).

**Statistical analysis**

The experiment was conducted as a completely randomised design with five dietary treatments and four replicates of 10 chicks each per treatment. One-way analysis of variance was carried out using the general linear model procedure of the SAS software (SAS 2004, NC, USA). Duncan's multiple range test was used to compare treatments. All differences were considered significant at p ≤ 0.05.

**Results**

**Growth performance results**

Mortality was 3.2% and was not related to experimental diets (data not shown). The data on performance traits of broilers are shown in Table 3. The inclusion of rice hulls in the diet tended to increase ADFI of broilers at finisher (24–42 d) and whole the experimental period (11–42 d) but at the grower phase only the diet with 1.5% rice hulls had the same effect (p < 0.05). The inclusion of barley hulls in the diets did not alter feed intake as compared with the control diet. From day 11 to 24, the inclusion of dietary hulls had no effect on BWG; however, from day 24 to 42 and also day 11 to 42 the broilers fed the diet contained 1.5% rice hulls had a higher BWG than the control group (p < 0.05). Fibre inclusion did not affect FCR from day 11 to 24. From day 25 to 42 and also the whole experimental period, FCR improved in birds fed the diet with 1.5% barley hulls but the only significant difference was observed with birds fed the diet with 1.5% rice hulls (p < 0.05). Figure 1 show that the feed cost per kg weight gain of broilers fed the diets contained 0.75% barley hulls and 0.75% or 1.5% rice hulls, were lower than the control group.

**Table 2. The composition of experimental diets.**

| Ingredient | Starter | Grower | Finisher |
|------------|---------|--------|----------|
|            | 75 g/kg | 150 g/kg | 75 g/kg | 150 g/kg | 75 g/kg | 150 g/kg |
| Barley hulls | 0 | 0 | 0.75 | 1.5 | 0 | 0 |
| Rice hulls | 0 | 0 | 0 | 0 | 0.75 | 1.5 |
| Corn | 45.92 | 48.55 | 47.06 | 45.86 | 47.19 | 46.11 |
| Soybean meal | 43.83 | 40.29 | 40.56 | 40.78 | 40.44 | 40.53 |
| Soybean oil | 5.88 | 7.19 | 7.68 | 7.94 | 7.67 | 7.91 |
| DCP | 2.09 | 1.72 | 1.71 | 1.7 | 1.72 | 1.72 |
| Calcium carbonate | 1.19 | 1.07 | 1.05 | 1.04 | 1.05 | 1.04 |
| Common salt | 0.23 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 |
| Vitamin premixa | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Mineral premixa | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| DL-Methionine | 0.32 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| HCL-Lysin | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |

### Chemical analysis

| Ingredient | Metabolisable energy, Kcal/kg | Crude protein, % | Ca, % | AvP, % | Na, % | Lys, % | Met, % | Met + Cys, % | CF, % | NDF, % | ADF, % | Lignin, % |
|------------|-----------------------------|-----------------|-------|--------|------|-------|-------|------------|------|--------|--------|---------|
| Starter    | 2980 | 3100 | 3100 | 3090 | 3100 | 3090 | 3130 | 3130 | 3130 | 3130 | 3130 | 3130 |
| Grower     | 23.27 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 |
| Finisher   | 1.033 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
|            | 0.52 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 |
|            | 0.198 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
|            | 1.41 | 1.297 | 1.297 | 1.304 | 1.297 | 1.304 | 1.297 | 1.304 | 1.297 | 1.304 | 1.297 | 1.304 |
|            | 0.69 | 0.5992 | 0.5992 | 0.5992 | 0.5992 | 0.5992 | 0.5992 | 0.5992 | 0.5992 | 0.5992 | 0.5992 | 0.5992 |
|            | 1.06 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
|            | 4.7 | 4.49 | 4.58 | 4.64 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 |
|            | 11.61 | 11.44 | 11.70 | 11.96 | 11.87 | 12.31 | 11.45 | 11.70 | 11.95 | 11.88 | 12.30 | 11.30 |
|            | 5.01 | 4.80 | 4.95 | 5.11 | 5.19 | 5.59 | 4.6 | 4.81 | 4.96 | 5.05 | 5.44 | 5.44 |
|            | 0.67 | 0.61 | 0.72 | 0.83 | 0.80 | 0.99 | 0.61 | 0.72 | 0.83 | 0.80 | 0.97 | 0.97 |

**Vitamin premix** provided the following per kilogram of diet: vitamin A (retinyl acetate): 9000 U; vitamin D (cholecalciferol): 5500 U; vitamin E (dl-a-tocopheryl acetate): 68 U; menadione: 9.0 mg; pyridoxine: 7.0 mg; riboflavin: 26.0 mg; Ca-pantothenate: 26.3 mg; biotin: 0.41 mg; thiamine: 3.66 mg; niacin: 75 mg; cobalamin: 0.03 mg and folic acid: 3.70 mg.

**Mineral premix** provided the following per kilogram of diet: Fe: 82 mg; Mn: 60 mg; Zn: 115 mg; Cu: 15 mg; I: 0.85 mg and Se: 0.4 mg.
The diets contained 1.5% barley hulls or 0.75% rice hulls reduced total intestine weight than control diet (p < 0.05) whereas no effect was observed for carcass, gizzard or abdominal fat pad weights (Table 4).

Fibre inclusion improved the digestibility coefficients of DM and ash (p < 0.05), the exceptions were the 1.5% rice hulls diet for DM and the 0.75% barley hulls diet for the ash digestibility coefficients, where showed no difference with the control diet (Table 5). The inclusion of rice hulls improved CP digestibility than the barley hulls contained diet and also the control diet (p < 0.05). The dietary fibre did not affect crude fat digestibility irrespective of type or level of fibre.

The duodenum and jejunum villous height (VH) decreased by dietary fibre than the control group (p < 0.05), however in the ileum, the only significant difference was observed with the birds fed the diet with 0.75% barley hulls and the control birds (p < 0.05) (Table 6). In the duodenum, rice hulls resulted in taller VH than the barley hulls (p < 0.05). The rice hulls contained diets increased the crypt depth (CD) in duodenum and the 0.75% level was more effective (p < 0.05). In the jejunum, the only difference was the lower CD in birds fed the 1.5% barley hulls (p < 0.05) and no difference were observed in CD between experimental groups in ileum segment. The lowest CD:VH ratio in the duodenum and jejunum segments were found in the control and 1.5% barley hulls groups, respectively (p < 0.05), and no difference were observed for this parameter in the ileum.

### Discussion

The inclusion of 0.75–1.5% rice or barley hulls improved BWG and FCR, indicating that broilers need a minimal dietary fibre in the diet to maximise growth performance. However, the effects depended on the source of fibre and the level of dietary inclusion. Rice hulls inclusion increased feed intake and weight gain but barley hulls improved FCR of broilers from 11 to 42 d of age and for the entire experimental period. The higher dietary dosage of both hulls was more effective. This observation agrees with data of Gonzalez-Alvarado et al. (2010) who indicated that the BWG increased more with the inclusion in the diet of an insoluble fibre source (oat hulls). Under the commercial management and nutritional practises, broilers chickens eat to gut fill (Ferket & Gernat 2006) because feed intake is regulated mainly by the physical capacity of the GIT (Nir et al. 1996). Dietary insoluble fibre will get faster the passage rate of the digesta through the distal part of the GIT which in turn may result in higher feed intake (Montagne et al. 2003; Hetland et al. 2004). Rice hulls have a higher lignin content (26%) than barley husks (15.5%), however, the same of cellulose and hemicelluloses in barley husks is more than rice husks (73 and 50%, respectively) (Barry et al.

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**Table 3.** Experiment performance characteristics of birds.

|                     | Daily feed intake (g/b/d) | Daily weight gain (g/b/d) | Feed conversion ratio |
|---------------------|---------------------------|---------------------------|----------------------|
|                     | 11–24 d | 25–42 d | 11–42 d | 11–24 d | 25–42 d | 11–42 d | 11–24 d | 25–42 d | 11–42 d |
| C                   | 81.67b | 166.81c | 126.53b | 54.58  | 87.95b  | 72.23b  | 1.49  | 1.89ab | 1.75ab  |
| LBH                 | 82.67b | 166.30c | 128.52b | 54.60  | 91.51ab | 74.59ab | 1.51  | 1.81ab | 1.72ab  |
| HBH                 | 80.50b | 165.33c | 127.25b | 55.09  | 92.11ab | 75.48ab | 1.46  | 1.79b  | 1.68b   |
| LRH                 | 81.04b | 174.98a | 131.74a | 53.36  | 92.53ab | 74.05ab | 1.51  | 1.90a  | 1.79a   |
| HRH                 | 85.61b | 169.96a | 131.69a | 56.33  | 93.61ab | 76.69a  | 1.52  | 1.84ab | 1.71ab  |
| MSE                 | 0.97   | 1.05   | 1.12    | 1.13   | 1.62    | 1.38    | 0.03  | 0.04   | 0.03    |

C: Control; LBH: the diet contained low level of barley hulls (0.75%); HBH: the diet contained high level of barley hulls (1.5%); LRH: the diet contained low level of rice hulls (0.75%); HRH: the diet contained high level of rice hulls (1.5%). Within a column not sharing a common superscript differ significantly at p < 0.05.

**Table 4.** Carcass and organ weight of experimental birds (% of live weight).

|         | Carcass | Whole intestine | Gizzard | Fat pad |
|---------|---------|----------------|---------|---------|
| C       | 59.2    | 7.83b          | 1.26    | 1.35    |
| LBH     | 60.1    | 7.29ab         | 1.27    | 1.37    |
| HBH     | 59.6    | 6.95b          | 1.27    | 1.33    |
| LRH     | 59.5    | 6.80b          | 1.20    | 1.34    |
| HRH     | 59.7    | 7.38ab         | 1.25    | 1.44    |
| MSE     | 0.88    | 0.22           | 0.06    | 0.14    |

C: Control; LBH: the diet contained low level of barley hulls (0.75%); HBH: the diet contained high level of barley hulls (1.5%); LRH: the diet contained low level of rice hulls (0.75%); HRH: the diet contained high level of rice hulls (1.5%).

**Table 5.** Nutrient digestibility coefficients of experimental diets.

| Nutrients digestibility coefficients (%) | Crude protein | Ether extract | Ash | Dry matter |
|-----------------------------------------|---------------|---------------|-----|------------|
| C                                       | 63.51b        | 80.75         | 36.27b | 73.13b    |
| LBH                                     | 63.55b        | 81.25         | 38.23cd | 75.26a    |
| HBH                                     | 63.60b        | 81.70         | 38.50e  | 75.40a    |
| LRH                                     | 71.03a        | 80.11         | 47.84a  | 76.45a    |
| HRH                                     | 71.50a        | 78.93         | 40.97de | 74.83ab   |
| MSE                                     | 0.81          | 0.57          | 0.65   | 0.59      |

C: Control; LBH: the diet contained low level of barley hulls (0.75%); HBH: the diet contained high level of barley hulls (1.5%); LRH: the diet contained low level of rice hulls (0.75%); HRH: the diet contained high level of rice hulls (1.5%).

a,bMeans within a column not sharing a common superscript differ significantly at p < 0.05. Relative weights are calculated as a percentage of BW.
These findings suggest that dietary lignin was more effective in increasing feed intake and weight gain than cellulose and hemicelluloses content.

It is well known that broilers eat to meet their energy requirements and once the dietary energy is diluted due to an increase in the fibre content of the diet, they acclimatise to the new condition by rising feed intake (Ferket & Gernat 2006). However, unlike the majority of the previous reports, in the current trial, the fibre sources were used to formulate isoricotic experimental rations and were not added as additives and diluting factors. It, therefore, seems that the feed intake promoting the effect of dietary fibre is not only because of a diluting effect and the nature of the fibre play an important role in this respect. Jiménez-Moreno et al. (2008) found higher daily feed intake and improved FCR in broilers when the basal diet was diluted with 50 g/kg of rice hulls or sunflower hulls per kg. In contrast in the current trial, barley hulls inclusion did not affect feed intake in any of the periods studied, but at 15 g/kg level improved FCR, results that are consistent with data of González-Moreno et al. (2007, 2010). These data suggest that moderate amounts of barley hulls versus rice hulls (7.5–15 g/kg) in current trial had little impact on feed consumption. The effect of moderate dosage of rice hulls on feed intake is comparable to a higher dietary inclusion (50 g/kg) of oat hulls in the trial of Jiménez-Moreno et al. (2008).

The majority reports showing positive effects of dietary fibre on broiler performance have been carried out with young chicks (González-Alvarado et al. 2007; Jiménez-Moreno et al. 2008; Amerah et al. 2009). The results of the present experiment show hopeful effects of fibre inclusion in grower and finisher diets of broiler chickens. The comparison between the two dietary fibre inclusion levels regardless of the fibre sources tested showed that the 15 g/kg dietary hulls level was more effective in improving chickens performance than the 7.5 g/kg level. Rice hulls inclusion increased ADFI indicating that the less bulky digesta produced when rice hulls was fed might increase passage rate and consequently, feed intake. Singh and Narang (1991) found water holding capacity (WHC) to be significantly correlated with NDF. Then, these results are consistent with higher NDF of barley hulls (88%) than rice hulls (76%) (Barry et al. 2001; Sun et al. 2002).

Broilers at finisher phase of rearing period might be eating close to their physical capacity and because of the higher NDF (and WHC) of the barley hulls, they are less able to adapt their feed intake to meet energy needs than chicks fed rice hulls containing diets. These results may explain, at least in part, the lower daily feed intake and weight gain of the barley hulls fed chickens in the current study. However, this is not the whole story. The calculations in the current study showed that the feed cost per kg weight gain of broilers was reduced in three of four hulls contained diet. This finding suggests that the economic profit must also be considered when evaluating the dietary fibre effects.

The digestibility coefficients of DM, ash and CP of the experimental diets was higher than the control diet but no differences were detected for the crude fat digestibility, suggesting that fibre inclusion increased the digestibility of dietary components. Results that are in agreement with the study of González-Alvarardo et al. (2007) and Amerah et al. (2009) in younger chickens. The beneficial effects of fibre inclusion on DM, ash and CP digestibility were more evident with rice hulls than with barley hulls inclusion, which is in agreement with more favourite performance data of rice hulls fed chickens in the current study. The positive effect of dietary fibre on CP digestibility is consistent with a raise in pepsin activity as a result of a higher HCl production (Gabriel et al. 2003).

In the present experiment, soluble ash retention increased with rice hulls inclusion suggesting that HCl production was higher for these diets. In a comparable observation, Jiménez-Moreno et al. (2010) found that the HCl concentration in the digesta of the gizzard was greater in chicks fed sugar beet pulp than in chicks fed the control diet, and Guinotte et al. (1995) showed

| Table 6. Small intestinal morphology of experimental birds. | Duodenum | Jejunum | Ileum |
|-----------------------------------------------------------|----------|---------|-------|
| VH (µm)                                                   | CD (µm)  | VH/CD   | VH (µm) | CD (µm) | VH/CD   | VH (µm) | CD (µm) | VH/CD   |
| C                                                        | 1738*    | 141*    | 0.081b | 842*    | 143*    | 0.169* | 778*    | 101     | 0.130  |
| BSL                                                      | 1594*    | 147b*   | 0.092a | 827b    | 139a    | 0.168a | 716b    | 103     | 0.144  |
| BSH                                                      | 1578*    | 142*    | 0.090a | 822b    | 131b    | 0.160b | 751b    | 97      | 0.129  |
| RSL                                                      | 1713b    | 157*    | 0.091a | 824b    | 145*    | 0.176a | 769b    | 105     | 0.131  |
| RSH                                                      | 1711b    | 152b    | 0.088a | 823b    | 143*    | 0.174a | 766b    | 101     | 0.131  |
| MSE                                                      | 6.16     | 1.75    | 0.001  | 4.03    | 2.02    | 0.002  | 18.2    | 2.08    | 0.005  |

*C: Control; LBH: the diet contained low level of barley hulls (0.75%); HBH: the diet contained high level of barley hulls (1.5%); LRH: the diet contained low level of rice hulls (0.75%); HRH: the diet contained high level of rice hulls (1.5%).

VH: villous height; CD: crypt depth.

Means within a column not sharing a common superscript differ significantly at \( p < 0.05. \)
in chicks that calcium solubilisation was reduced when HCl secretion was decreased. As a result, the addition of fibre to the diet might benefit CP digestibility in broilers as has been demonstrated by González-Alvarado et al. (2007) and Jiménez-Moreno et al. (2009b) in chicks.

In the present study, dietary fibre did not affect crude fat digestibility irrespective of the type of fibre. However, Hetland et al. (2003) reported that dietary fibre enhanced the quantity of bile acids present in the gizzard digesta and Mosenthin et al. (1999) found a higher biliary and pancreas secretions in pigs after the dietary fibre increased. In the current study, the effects of fibre on the development of the GIT did not vary with the type of fibre; both the fibre sources inclusion reduced total intestine weight than control diet whereas the no effect was observed for gizzard weight. Jørgensen et al. (1996) showed that the size of the GIT increased more with the inclusion in the diet of a soluble fibre source (pea hulls) than of a more insoluble fibre source (oat bran). Insoluble fibre sources, particularly those with high lignin content, such as oat hulls, are more coarse and resistant to grinding and had lower WHC than more soluble fibre sources, such as sugar beet pulp (Bach Knudsen & Jørgensen 2001). The inclusion of fibre in the diet did not affect the weight of the gizzard, results that are not consistent with studies of Hetland et al. (2003) and González-Alvarado et al. (2008). The data indicate that the magnitude of the response may be depended on the dietary fibre particle size. These results indicate that gizzard development is stimulated by dietary fibre coarse nature and fine ground fibre is not pronounced in this respect. The large hull particles are kept in the gizzard until they are ground to a particular critical size that allows them to pass through the pyloric sphincter (Clemens et al. 1975; Moore 1999; Hetland et al. 2003). This leads to an enlargement of the organ and a muscular adaptation to meet the higher demand for grinding.

Rezaei et al. (2011) reported that chickens fed the fine hull diet had heavier gizzards than those of the control diet, suggesting that the fine particles were also retained and somewhat induced the gizzard enlargement. The finding which is not consistent with the fine fibre particle effects in the current study. Hetland et al. (2003) found that the average duodenal particle size for chickens fed an experimental diet with ground or whole oat hulls was between 120 and 127 \( \mu m \). This confirmed a previous report that declared that 90% of duodenal particles were less than 300 \( \mu m \) (Hetland et al. 2002) and suggested that hulls ground through a 1-mm sieve were coarse enough to be kept in the gizzard as a grinding medium. An observation which we could not reproduce using the same sieve size with rice or barley hulls.

In jejunum, as the major absorptive section of the small intestine, although the inclusion of hulls in broiler diets decreased VH than the control group, the 1.5% barley hulls significantly decreased the CD and resulted in a more favourite CD:VH ratio. The inclusion of 1.5% dietary barley hulls thus improved the mucosal absorptive surface area (Dibner et al. 1996). The lower loss of scratched enterocytes from the villus decrease the mitosis rate in crypt cells, as evidenced by the decrease in CD observed in the group fed the 1.5% barley hulls to compensate for the lost cells. The crypt can be regarded as the villous factory; a shallow crypt
shows slower tissue turnover and a less demand for new tissue (Xu et al. 2003). Therefore, decrease CD in the birds fed 1.5% barley hulls suggests a lower proliferative potential (Iji et al. 2001). Any further tissue turnover will enhance the quantity of nutrients necessary for maintenance and will lower the efficiency of the animal (Xu et al. 2003). A shorter VH is associated with decreased intestinal absorptive capability (Mathlouthi et al. 2002) and absorptive surface area (Xu et al. 2003). However, the CD:VH ratio is an indicator of the digestive potential of the small intestine (Adibmoradi et al. 2006). A lower CD:VH ratio is indicative of improved function and maturity of the intestinal mucosa (Hampson 1986). Thus, the inclusion of 1.5% barley hulls might have contributed to the greater BWG (statistically insignificant) and lower FCR.

Conclusions

Kind of fibre influenced performance and digestive traits of broilers with effects varying in accordance with the level of fibre. Rice hulls inclusion consistently improved growth performance and CP digestibility in broilers regardless of dietary inclusion level. However, barley hulls at 1.5% level improved CD: VH ratio and FCR but has an opposite effect on VH. The beneficial effects of hulls were more obvious with the 1.5% dietary inclusion level than the 0.75% level.

The useful effects of rice hulls inclusion on broiler efficiency was mainly because of its effect on CP digestibility while barley hulls at 1.5% level positively changed jejunum morphology. The data suggest that broilers may have a nominal requirement for insoluble fibre, however, the source and dietary inclusion rate of fibre might be important factors to satisfy dietary fibre requirements in birds.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

References

Adibmoradi M, Navidshad B, Seifdavati M, Royan M. 2006. Effect of dietary garlic meal on histological structure of small intestine in broiler chickens. J Poult Sci. 43:378–383.

Amerah AM, Ravindran V, Lentle RG. 2009. Influence of insoluble fibre and whole wheat inclusion on the performance, digestive tract development and ileal microbiota profile of broiler chickens. Br Poult Sci. 50:366–375.

AOAC. 2000. Official methods of analysis. 17th ed. Washington (DC): AOAC.

Aviagen. 2009. Ross 308 broiler nutrition specifications; [cited Jul 2014]. http://en.aviagen.com/ross-308/.

Bach Knudsen KE, Jørgensen H. 2001. Intestinal degradation of dietary carbohydrates – from birth to maturity. In: Lindberg JE, Ogle B, editors. Digestive physiology of pigs. Wallingford (CT): CABI Publishing. p. 109–120.

Barry V, McCleary B, Prosky L. 2001. Advanced dietary fibre technology. Oxford (UK): Blackwell Science Press.

Boletín Oficial del Estado. 1995. Real Decreto 2257/1994 por el que se aprueba los métodos oficiales de análisis de piensos o alimentos para animales y sus primeras materias. BOE Report No. 199552, pp. 7161–7237.

Clemens ET, Stevens CE, Southworth M. 1975. Sites of organic acid production and pattern of digesta movement in the gastrointestinal tract of geese. J Nutr. 105:1341–1350.

Dibner JJ, Kitchell ML, Atwell CA, Ivey FJ. 1996. The effect of dietary ingredients and age on the microscopic structure of the gastrointestinal tract in poultry. J Appl Poult Res. 5:70–77.

Fenton T, Fenton M. 1979. An important procedure for the determination of chromic oxid in feed and feces. Can J Anim Sci. 59:631–634.

Ferket PR, Gernat AG. 1996. Factors that affect feed intake of meat birds: a review. Int J Poult Sci. 5:905–911.

Gabriel I, Mallet S, Leconte M. 2003. Differences in the digestive tract characteristics of broiler chickens fed on complete pelleted diet or on whole wheat added to pelleted protein concentrate. Br Poult Sci. 44:283–290.

González-Alvarado JM, Jiménez-Moreno E, Lázaro R, Mateos GG. 2007. Effect of type of cereal, heat processing of the cereal, and inclusion of fiber in the diet on productive performance and digestive traits of broilers. Poult Sci. 86:1705–1715.

González-Alvarado JM, Jiménez-Moreno E, Valencia DG, Lázaro R, Mateos GG. 2008. Effects of fiber source and heat processing of the cereal on the development and pH of the gastrointestinal tract of broilers fed diets based on corn or rice. Poult Sci. 87:1779–1795.

González-Alvarado JM, Jiménez-Moreno E, González-Sánchez D, Lázaro R, Mateos GG. 2010. Effect of inclusion of oat hulls and sugar beet pulp in the diet on productive performance and digestive traits of broilers from 1 to 42 d of age. Anim Feed Sci Technol. 162:37–46.

Guinotte F, Gautron J, Nys Y. 1995. Calcium solubilization and retention in the gastrointestinal tract in chicks (Gallus domesticus) as a function of gastric acid secretion inhibition and of calcium carbonate particle size. Br J Nutr. 73:125–139.

Hampson DJ. 1986. Alteration in piglet small intestine structure at weaning. Res Vet Sci. 40:32–40.

Hetland H, Svihus B, Olaisen V. 2002. Effect of feeding whole cereals on performance, starch digestibility and duodenal particle size distribution in broiler chickens. Br Poult Sci. 43:416–423.

Hetland H, Svihus B, Krogdalhl A. 2003. Effects of oat hulls and wood shavings on digestion in broilers and layers fed diets based on whole or ground wheat. Br Poult Sci. 44:275–282.

Hetland H, Choc M, Svihus B. 2004. Role of insoluble non-starch polysaccharides in poultry nutrition. World Poult Sci J. 60:415–422.

Hetland H, Svihus B, Choc M. 2005. Role of insoluble fibre on gizzard activity in layers. World Poult Sci J. 60:415–422.
Iji PA, Sakim AA, Tivey DR. 2001. Intestinal development and body growth of broiler chicks on diets supplemented with non-starch polysaccharides. Anim Feed Sci Technol. 89:175–188.

Jiménez-Moreno E, González-Alvarado JM, de Coca-Sinova A, Pérez-Serrano A, Lázaro R, Mateos GG. 2008. Influence of feed form and fibre inclusion in the diet on water and feed intake of chicks. Poult Sci. 80:92–93.

Jiménez-Moreno E, González-Alvarado JM, González-Serrano A, Lázaro R, Mateos GG. 2009a. Effect of dietary fiber and fat on performance and digestive traits of broilers from one to twenty-one days of age. Poult Sci. 88:2562–2574.

Jiménez-Moreno E, González-Alvarado JM, Lázaro R, Mateos GG. 2009b. Effects of type of cereal, heat processing of the cereal, and fibre inclusion in the diet on gizzard pH and nutrient utilization in broilers at different ages. Poult Sci. 88:1925–1933.

Jiménez-Moreno E, González-Alvarado JM, González-Sanchez D, Lázaro R, Mateos GG. 2010. Effect of type and particle size of fibre source of the diet on productive performance and digestive traits of broilers from 1 to 21 days of age. Poult Sci. 89:2197–2212.

Jørgensen H, Zhao XQ, Eggum BO. 1996. The influence of dietary fibre and environmental temperature on the development of the gastrointestinal tract, digestibility, degree of fermentation in the hind-gut and energy metabolism in pigs. Br J Nutr. 75:365–378.

Mathlouthi N, Lalle JP, Lepercq P, Juste C, Larbier M. 2002. Xylanase and beta-glucanase supplementation improve conjugated bile acid fraction in intestinal contents and increase villus size of small intestine wall in broiler chickens fed a rye-based diet. J Anim Sci. 80:2773–2779.

Montagne L, Pluske JR, Hampson DJ. 2003. A review of interactions between dietary fibre and the intestinal mucosa, and their consequences on digestive health in young non-ruminant animals. Anim Feed Sci Technol. 108:95–117.

Moore SJ. 1999. Food breakdown in an avian herbivore: who needs teeth? Aust J Zool. 47:625–632.

Mosenthin R, Hambrecht E, Sauer WC. 1999. Utilization of different fibres in piglets feeds. In: Garnsworthy PC, Wiseman J, editors. Recent advances in animal nutrition. Nottingham, UK: Nottingham University Press. p. 227–256.

Navidshad B, Liang JB, Faseleh Jahromi M, Akhlaghi A, Abdullah N. 2015. A comparison between a yeast cell wall extract (Bio-Mos®) and palm kernel expeller as mannan-oligosaccharides sources on the performance and ileal microbial population of broiler chickens. Ital J Anim Sci. 14:e3452.

Nir I, Nitsan Z, Dunnington EA, Siegel PB. 1996. Aspects of food intake restriction in young domestic fowl: metabolic and genetic considerations. World Poult Sci J. 52:251–266.

Rezaei M, Karimi Torshizi MA, Rouzbehyan Y. 2011. The influence of different levels of micronized insoluble fiber on broiler performance and litter moisture. Poult Sci. 90:2008–2012.

Rougière N, Carré B. 2010. Comparison of gastrointestinal transit times between chickens from D+ and D− genetic lines selected for divergent digestion efficiency. Animal. 4:1861–1872.

SAS. 2004. Institute. SAS User’s Guide. Statistics, Version 9. 22004 ed. Cary (NC): SAS Institute Inc.

Schneeman BO. 2001. Dietary fibre and gastrointestinal function. In: McLeary BV, Prosky L. editors. Advanced dietary fibre technology. Oxford, UK: Blackwell Science Ltd. p. 168–176.

Sibbald IR. 1976a. The effect of the duration of starvation of the assay bird on true metabolizable energy values. Poult Sci. 55:1578–1579.

Sibbald IR. 1976b. The true metabolizable energy values of several feeding stuffs measured with roosters, laying hens, turkeys and broiler hens. Poult Sci. 55:1459–1463.

Singh B, Narang MP. 1991. Some physico-chemical characteristics of forages and their relationships to digestibility. Indian J Anim Nutr. 8:179–186.

Sun RC, Sun XF, Fowler P, Tomkinson J. 2002. Structural and physico-chemical characterization of lignins solubilized during alkaline peroxide treatment of barley straw. Eur Polym J. 38:1399–1407.

Van Soest PJ, Robertson JB, Lewis BA. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J Dairy Sci. 74:3583–3597.

Xu ZR, Hu CH, Xia MS, Zhan XA, Wang MQ. 2003. Effects of dietary fructooligosaccharide on digestive enzyme activities, intestinal microflora and morphology of male broilers. Poult Sci. 82:1030–1036.