Effects of different inclusions of oat hulls on performance, carcass yield and gut development in broiler chickens

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Abstract

An experiment was conducted to determine the effects of oat hulls (OH) as a model of insoluble fiber on performance, carcass and gastrointestinal tract morphologic traits in broiler chickens kept in pens with access to wood shavings as litter substrate. The temperature was set to 32°C at day 0 and gradually decreased to 23°C at day 30 and onwards. Five dietary treatments including 0, 2, 4, 6 and 8% of oat hull with five replicates of eight chickens per replication were fed for 35 days. The results indicated that feed intake (FI) was significantly increased with 4 and 6% OH inclusion in the diet. Furthermore, feed conversion ratio (FCR) significantly increased with 6% OH inclusion in the diet. This inclusion also had a significant effect on weight and length of ileum. Also weight of jejunum with digesta was significantly increased with 8% inclusion of OH in the diet. The weight of the whole gastrointestinal tract (GIT) with digesta tended to increase with OH inclusion in the diet. Gizzard + proventriculus weight without digesta content tended to increase with oat hull inclusion. Duodenal pH was increased by OH inclusion in diet. Water holding capacity of feed was significantly increased due to the OH inclusion in diet and results showed that OH inclusion in diet can increase water absorption of feed. This may increase the retention time of ingesta in the upper part of the digestive tract (from crop to gizzard) and stimulate gizzard function and proventricular secretion of HCl, thereby hypothetically improving digestion. Although consumption of wood shavings was not measured in the current study, some wood shaving particles was observed in the gizzard during dissection at day 35.

Introduction

Improving feed conversion is one of the most important targets of commercial poultry nutrition. However this is only acquired if chicken health is assured. The health and welfare of poultry are main issues in nutritional management. Broiler chicken diets are characterized by high nutrient densities with low fiber contents. To date, several reports have investigated beneficial effects of adding oat hulls, or other types or fibrous fractions into the diet of broiler chickens (Rogel *et al*., 1987 and Hetland *et al*., 2004). Adding fibrous feedstuffs dilutes the diet and may improve the motility and function of the gastrointestinal tract (GIT). Studies by several researchers (Hetland and Svihus 2001and Shakouri *et al*., 2006) reported that fiber inclusion diet did not compromise growth in broiler chickens. The beneficial effects of fiber were also shown to be related to decreased gizzard pH, which was accompanied by enhanced nutrient utilization to support and/or increase growth (González *et al*., 2007).

Fiber inclusion via oat hull elevated the retention time in the upper section of the digestive tract (from crop to gizzard) and stimulated the gizzard function and HCl production in proventriculus (Rogel *et al*., 1987 and Jiménez *et al*., 2009).

Moreover, low pH in the upper GIT resulted in optimized solubility and absorption of salts (Jiménez *et al*., 2009). Oat hull contains insoluble fiber (>95%), cellulose and xylans (Lopez-Guisa *et al*., 1988). Insoluble fibers increase the water holding capacity of digesta in the gut (Montagne *et al*., 2003). Moreover, fiber can provide a fermentative substrate for the large

intestinal flora, and a healthy microflora may decrease the incidence of intestinal problems such as necrotic enteritis (Mateos *et al*., 2002).

The digestive tract in broiler chickens

The digestive tract of poultry categorizes broiler chickens as monogastric (non-ruminant) animals. Therefore, poultry have a limited capacity to digest cellulose and other complex carbohydrates in comparison with ruminants. Feed digestion includes the physical and enzymatic breakdown of feed ingredients such as plants and animal substances. This breakdown produces chemical elements which are small enough to be taken up through villi in the gut wall and into the blood stream (Rose 2005).

In birds the beak functions in a similar fashion to the lips and cheeks of mammals, hence there are no teeth and taste is limited. The taste buds are placed in the back half of the tongue. The crop is a diverticulum of the esophagus, and its main function is to store the feed. The crop wall does not have mucus-secreting glands. Salivary amylase is secreted in birds and its action continues in the crop. The esophagus ends at the proventriculus or glandular stomach. Here, the glands secrete pepsinogen and hydrochloric acid (HCl). The proventriculus has very small natural mobility and feed passes through it due to esophageal contractions. Following the proventriculus the gizzard is a muscular organ with inner ridges which contracts rhythmically and grinds the wet feed into a smooth paste (McDonald *et al*., 2002).

The small intestine includes three segments; duodenum from the gizzard to the entrance of the bile via hepatic ducts, jejunum from entry of the ducts to Meckel's diverticulum and ileum from Meckel's diverticulum to the ileocecal junction (Soltan 2009). Feed particles leave the gizzard and enter the duodenum into which pancreatic enzymes and bile acids are secreted. Large proportions of digestive enzymes which hydrolyse carbohydrates, proteins and fats are secreted from the small intestine. Muscular contractions waves, i.e. duodenal peristalsis, refluxes duodenal contents into the gizzard, thereby increasing fat hydrolysis and absorption (Rose 2005). The large intestine in poultry consists of rectum, colon and two caeca. The caeca are located at the junction of the small and large intestine (Sturkie 1986). Microbial fermentation occurs in the caeca in non-ruminants. The colon is the main place for water absorption. Residual undigested feed, urine and faeces are collected in cloacae (Rose 2005). The whole digestive tract is illustrated in Figure 1.

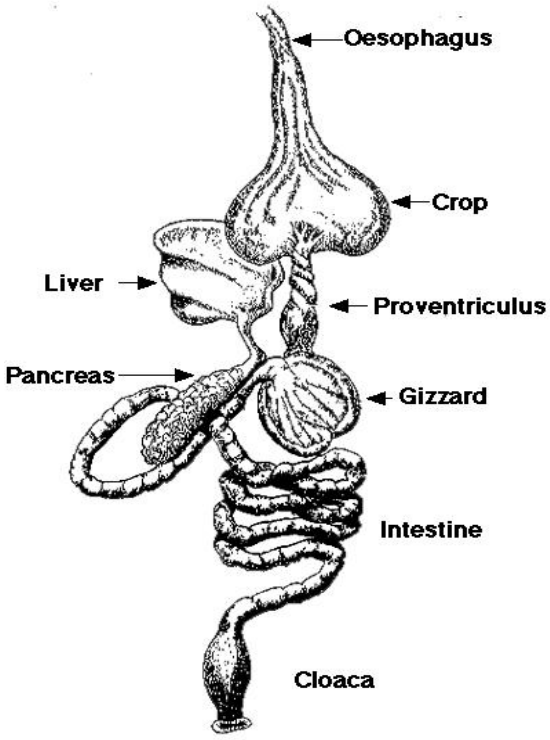

Figure 1. The gastrointestinal tract of poultry
Source: http://numbat.murdoch.edu.au/Anatomy/avian/fig4.1.GIF

Oats and oat hulls

Oats are less commonly used in feed for pigs and poultry due to the high content of fiber and low energy value in comparison with other cereals (McDonald *et al*., 2002; McNab and Boorman, 2002). The hull part of the oat plays an important role in the nutritive value of this cereal. Cereal and the nutritive value depend on the ratio of kernel to hull. Moreover, the ratio of hull weight in the grain is influenced by different factors such as variety, environment and season, and may vary from 23 to 35%, the average being 27% (McDonald *et al*., 2002). Oats which have a higher hull content have a larger quantity of crude fiber and less metabolizable energy value compared to oats which are less-hulled. Oats contain more lysine compared to other cereals. Oat hull has a very low feeding value: the crude protein of oat hull is around 30 g/kg DM, and the crude fiber is between 350 and 380 g/kg DM (McDonald *et al*., 2002). As showed by Lopez-Guisa *et al*. (1988) oat hull contains more than 95% insoluble fiber. Therefore oat hull can be considered as insoluble fiber.

Glutamic acid is the most abundant amino acid in protein of oat and comprises about 200 g/kg protein. Oat hull and meal seeds are the major by-products of oats. Meal seeds consist of slivers of husk and fragments of kernel in approximately equal proportions (McDonald *et al*., 2002). Moreover, oat hull can be mixed with oat dust in the ratio of 4 to 1 and hence it could be sold as oat feed. This combination has better value than the hull alone from a nutritive

value point of view (McDonald *et al*., 2002). According to McNab and Boorman (2002), oats account for less than 5% of the total cereal grain production in the world. Oats contain a more favourable amino acid composition compared to maize.

Fiber

Fiber is a generic term which refers to the cell walls of plant tissue which include mainly lignin, cellulose and hemicelluloses (McDonald *et al*., 2002). Dietary fiber is a component of plants which is indigestible by endogenous enzymes (Sharikhan *et al*., 2009). Moreover, cellulose, hemicellulose and lignin constitute the components of neutral-detergent fiber (NDF), a residue from extraction with boiling neutral solutions of sodium lauryl sulphate and ethylenediamine tetra acetic acid, whereas lignin and cellulose constitute the components of acid detergent fiber (ADF), a residual after refluxing with sulphuric acid and cetyltrimethyl-ammonium bromide (McDonald et al., 2002).

According to McDonald *et al*. (2002) carbohydrates in feed include two fractions, crude fiber (CF) and nitrogen free extractive (NFE). Crude fiber is the residual fraction from boiling and extracting the feed with solvents and alkali (Trowell 1976). In addition, CF consists of a variable proportion of insoluble non starch polysaccharides (NSP) (Choct 1997). Crude fiber contains cellulose, hemicelluloses and lignin (McDonald *et al*., 2002; Sharikhan *et al*., 2009). In the nutrition of monogastric species, and especially in human nutrition, the term "dietary fiber" is used (McDonald *et al*., 2002).

The definition of dietary fiber is still discussed; therefore, several definitions are used. The most common definition of dietary fiber is the composition of plant cell wall residues that are resistant to enzymes in the small intestine. From a chemical point of view dietary fiber may also be described as non-starch polysaccharides (Thebaudin *et al*., 1997). The fraction non-starch polysaccharides (NSP) may be divided further into soluble and insoluble NSP (McNab and Boorman, 2002; McDonald *et al*., 2002).

Diets rich in soluble NSP increase the microbial fermentation in the intestine and may lead to increased risk for necrotic enteritis, an acute non-contagious disease in poultry (Branton *et al*., 1997) caused by *Clostridium perfringens* (McNab and Boorman, 2002; Montagne *et al*., 2002).

Cellulose is mainly water insoluble (Anderson and Chen, 1979) and it is an abundant organic compound in nature, including more than 50% of all the carbon in vegetation (Choct 1997). It is the fundamental structure of plant cell walls and its chemical components are polysaccharides containing β-(1,3)- and frequently β-(1,4)- linked glucose residues (McDonald *et al*., 2002). The term hemicellulose refers to alkali soluble cell wall polysaccharides which are connected with cellulose. Hemicelluloses are structured by D-glucose, D-galactose, D- mannose, D-xylose and L-arabinose units linked together in various combinations (McDonald *et al*., 2002). Lignin is a polymer, originated from coumaryl alcohol, coniferyl alcohol and sinapyl alcohol (McDonald *et al*., 2002).

Effects of soluble and insoluble fiber on the transit rate of digesta in the gut

According to Sarikhan *et al.* (2009) fiber is a nutritionally, chemically and physically heterogeneous material. It may be divided into soluble fibers which are viscous and fermentable, and insoluble fibers, which are less viscous and fermentable. Both soluble and insoluble fibers have various roles in the digestion and absorption processes in the gastrointestinal tract. Wheat bran and cellulose, which are categorized as insoluble fibers, elevate faeces weight and faecal bulk and decrease intestinal transit time in non ruminant animals (Thebaudin *et al*., 1997). Increased faecal bulk weight results from increased bacterial cell mass, undigested fiber and faecal water (Thebaudin *et al*., 1997; Montagne *et al*., 2002).

In humans, soluble fibers decrease intestinal transit time, pancreatic secretion and absorption rate; postpone gastric emptying and interfere with glucose absorption (Thebaudin *et al*., 1997; Montagne *et al*., 2002). Soluble fiber in cereals, particularly in wheat and barley, may have adverse effects on the GIT in poultry, such as reduced feed conversion and increased moisture and organic matter in faeces due to the high viscosity of soluble fiber (Montagne *et al*., 2002). Jørgensen *et al*. (1996) demonstrated that high ingesta viscosity in the chickens' GIT may depress the nutrient digestibility, as it is associated with suppressed digestive enzyme infusion in the GIT, and a decreased dry matter percentage of excreta in chickens.

A diet rich in soluble NSP increases fermentation and gut viscosity in broilers' small intestine. Viscosity of NSP varies with water solubility and molecular weights (Choct 1997). Therefore adding 3% soluble NSP in broilers' diet leads to energy loss through heat and volatile fatty acid (VFA) in the faeces (Choct *et al*., 1996). However, Choct *et al*. (1996) and McNab and Boorman (2002) suggested that adding exogenous enzymes (*i.e.*, glycanase and xylanase) would help overcoming the negative effects of soluble NSP, such as decreased weight gain and lowered apparent metabolizable energy (AME). Low AME, impaired nutrient absorption and increased incidence of wet droppings may occur due to increased gut viscosity related to feeding soluble NSP (Józefiak *et al*., 2006). Besides, Mikulski *et al*. (2006) reported that xylanase added in wheat based diet decreased caecal *Clostridium perfringens* and *Lactobacillus* counts due to the intestinal viscosity reduction.

An increased level of insoluble fiber in the broiler diet leads to an increased transit rate of digesta in the small intestine due to the high water holding capacity of insoluble fiber (Kirwan *et al*., 1974). However, Jiménez-Moreno *et al*. (2009) stated that oat hulls are much lignified and therefore oat hulls may have a lower water holding capacity and swelling water capacity (volumetric). Thus, a diet containing oat hulls would be retained longer in the gizzard due to being much lignified and more resistant to grinding. Addition of coarsely ground 10% oat hulls, which contains 90% NSP of which 99% are insoluble, in the diet may increase the passage rate of digesta in the small intestine (McNab and Boorman 2002). However, Hetland *et al*. (2005) stated that coarse particles of feed should be ground to a specific size before they can leave the gizzard. The gizzard increases in volume when physically stimulated by whole and insoluble fibers. Hetland *et al*. (2005) investigated the accumulation of fiber structures in the gizzard and concluded that the retention time of insoluble fiber was prolonged in

comparison with other nutrients. Whole cereals which chiefly contain starch granules and protein can, however, be dissolved quickly in the acidic gastric fluid in the gizzard and hypothetically pass quickly from the gizzard without any stimulation. Therefore gizzard activity may be more stimulated by fiber structures than with whole cereal structures (Hetland *et al*., 2005). As fiber accumulation in the gizzard increases digesta transit time in the upper GIT, this does not comply with the conventional theory that insoluble fibers accelerate digesta passage (Hetland *et al*., 2005). However this phenomenon only applies to coarse insoluble fiber fraction. A hypothesis was formulated by Hetland and Svihus (2001) and Svihus *et al*. (2002) that fine digesta particles were passed on more slowly from the gizzard when coarse particles were added in the feed. As a consequence, the effect of fiber content on the retention time of digesta in the gizzard of broilers is ambiguous, and motivates further studies.

Some reports claim that a longer retention of digesta in the gut leads to a more thorough digestion of diet due to long accessibility of gut microflora to digesta (McNab and Brooman, 2002). However this hypothesis is not acceptable in all circumstances. Insoluble NSP contains the cross linked matrix of the plant cell wall (Van Soest *et al*., 1991), which may aid the host in absorbing water and keeping a normal mobility of the gut. This is very important for excreta firmness in monogastric animals, and consequently also for excreta consistency (McNab and Brooman 2002).

Effects of insoluble fiber on digestion

Traditionally fiber is not recommended in poultry diet because poultry have a very limited capacity to digest the cellulose component of the feed (Jiménez-Moreno *et al*., 2009). In many countries wheat is the main ingredient in broiler and layer diets because of its high protein and starch content (Hetland *et al*., 2003). Occasionally, the digestibility of wheat starch has been considerably low, and some researchers have reported that whole grain improves the digestibility of starch, owing to the physical structures which stimulate gizzard activity.

Whole grains stimulate the proventriculus to produce more HCl and increase the secretion of amylase and bile salts in jejunal chyme, in a similar manner as coarsely ground oat hulls (Hetland and Svihus, 2001; Svihus and Hetland 2001; Svihus *et al*., 2002; Hetland *et al*., 2003; Hetland *et al*., 2005). Similarly, oat hulls improved the digestion of raw potato starch, via stimulation of the gizzard (Rogel *et al*., 1987). This stimulation promotes gizzard development and increases muscular contraction, making the breakdown of starch granules more efficient (Rogel *et al*., 1987; Rogel *et al*., 1987a). Oat hull contains about 50% hemicelluloses, and may improve the utilization of low quality starch (Rogel *et al*., 1987). The starch digestibility improvement depends on the level of oat hulls in the diet and the size of the hull particles. Therefore, coarse fiber (>1mm in length) was shown to be more effective than finely ground fiber particles in aiding the digestion of starch (Rogel *et al*., 1987a). Hetland *et al*. (2004) reported that feed particle size was important to the stimulation of the gizzard and the finest particles could not influence gizzard stimulation as much as large particles. This is because coarse particles stay longer than fine particles in the upper gastrointestinal tract (Jiménez-Moreno *et al*., 2009b). Moreover, large and coarse feed

particles were digested slowly in the proximal small intestine which may lead to more peristaltic movements, possibly aiding nutrient utilization (Dahlke *et al*., 2003). The experiment by Mollah and Annison (1981) indicated that the hemicellulose content in maize is more digestible than the hemicellulose content in wheat and an addition of 5% of oat hulls (hemicelluloses content 400 g/kg) in the wheat based diet enhanced the ileal digestibility of dietary hemicelluloses in the wheat from 8 to 14%. Fermentation of hemicelluloses in the digestive tract is essential for maintenance of a favorable intestinal microflora. Besides, Bryden *et al*. (1991) found that oat hull inclusion in broiler diets improved the starch digestibility with an accompanying elevation in AME of wheat. This increased starch digestibility was associated with an increased ileal pH.

Svihus *et al.* (2002) suggested that an active gizzard can stimulate the contraction of the small intestine, which leads to a speeding-up of the passage rate of digesta throughout the small intestine. This may decrease the proliferation of potentially detrimental microorganisms including *Clostridium perfringens*. Mikulski *et al*. (2006) declared that *Clostridium perfringens* infection in broilers leads to an impaired performance of production. An active gizzard could elicit contractions of the small intestine and consequently promote the ingesta flow (Svihus *et al*., 2002). One role of the gizzard is to regulate the motility of the gastrointestinal tract, suggesting that an underdeveloped gizzard is associated with depressed digestibility of nutrients and bird growth (González-Alvarado *et al*., 2008). Deficiency of gizzard development leads to occurrence of proventricular hypertrophy and dilatation (Riddell 1976) which might increase chicken mortality resulting from ascites through blockage of the thoracic cavity leading to an impaired function of heart and lung (Jones and Taylor 2001).

Hetland *et al*. (2003) reported that bile acid concentration in the gizzard was increased in birds fed oat hull. Total amounts of bile acids were over twofold in the gizzard of the birds fed oats in comparison with wheat (Hetland *et al*., 2005). Bile acids are secreted into the intestinal tract between duodenum and jejunum. An increased level of bile acids in the gizzard indicated an increased chyme reflux from duodenum to gizzard mediated by the inclusion of insoluble fiber in the diet (Hetland *et al*., 2004). In addition, digestive enzyme concentration can increase in the upper part of the digestive tract by increased reflux (Hetland *et al*., 2004). Possibly, the reflux of digesta into the upper part of the digestive tract prolongs digesta exposure to the enzymatic and mechanical system of the gastrointestinal tract (Sacranie *et al*., 2008). This circumstance can lead to an increased digestion and absorption time in the upper intestine (Sacranie *et al*., 2008). As suggested by Hetland *et al*. (2004) the gizzard plays a main role for digesta gastro-duodenal reflux and the gizzard might be unable to affect the digesta movements when lacking feed stimuli. That is, this hypothesis suggests that birds need to have structural components for provoking the anterior digestive tract, including the gizzard.

Taylor and Jones (2004) reported that an active gizzard increases the peristaltic movement of the intestine. Muscular actions grind the large starch granules and prepare them to amylolysis by pancreatic enzymes in the gut (Rogel *et al*., 1987a). Experiments by Riddell (1976) indicated that the gizzard musculature development was very deficient in the absence of fibers in the diet. In other studies, consumption of hulls and wood shavings resulted in elevated ileal

starch digestibility (Hetland *et al*., 2003; Hetland *et al*., 2004). It was concluded that the insoluble content of oat hulls may increase the secretion of amylase and bile acids, and thereby improve starch digestibility (Hetland *et al*., 2003). In addition, Rogel *et al*. (1987) reported antibacterial and antifungal properties of oat hulls.

Effects of insoluble fiber on gut volume, pH and intestinal morphology

Hetland and Svihus (2001) reported that an oat based poultry diet increased the relative weight of the gastrointestinal tract compared to a wheat based diet. Thus, an increased feed intake from feeding oat hulls could be related to an increased GIT volume (Hetland and Svihus, 2001). The gizzard weight was increased when broilers were fed dried cassava pulp (DCP) which is also a fibrous feedstuff (Khempaka *et al*., 2009). Khempaka *et al*. (2009) concluded that DCP may improve the GIT health and decrease abdominal fat deposit in broilers. Jørgensen *et al*. (1996) showed that a high dietary fiber intake led to significant expansion and increased length of the GIT; in particular the length of ceca. Gizzard hypertrophy occurs in birds fed oat hull (Rogel *et al*., 1987) and the weight and length of the small intestine is reduced (Rogel *et al*., 1987a). Similarly, De Verdal *et al*. (2010) reported that gizzard enlargement was associated with a reduced relative weight of the small intestine. However, the lengths of different segments of intestine were shown to increase when the broilers were fed dried cassava pulp, containing insoluble fibers (Khempaka *et al*., 2009).

Jiménez-Moreno *et al*. (2009) reported that fibrous ingredients such as oat hull and soy hull decreased the gizzard pH. Jiménez-Moreno *et al*. (2009a) indicated that oat hull (OH) and sugar beet pulp (SBP) significantly reduced gizzard pH compare to cellulose. Oat hull prolongs the digesta retention in the gizzard (Engberg *et al*., 2004). This leads to reductions in gizzard pH due to increased hydrochloric acid (HCl) secretion. Low pH in the gizzard is associated with increased mineral salts solubility which may ease digestion and absorption of minerals in the upper part of the GIT and promote pepsin activity (Guinotte *et al*., 1995). However, others have found no difference in the duodenum pH when fiber was added to broiler diets (Jiménez-Moreno *et al*., 2009a). Decreased gizzard pH was observed in response to a coarse particle size of the diet and this phenomenon may hypothetically improve the gut health by killing the bacteria through the acid environment in the intestinal tract (Engberg *et al*., 2004). Sarikhan *et al*. (2010) showed that insoluble fiber influenced villi height at day 21 and over 21 days of age. Sarikhan *et al*. (2010) reported that intestinal villi of broiler chickens were more developed when the birds were fed a high dietary fiber diet, leading to a faster growth rate. Coarse fiber and large particles may increase villi length in gastrointestinal tract. Therefore increased villi length resulted in increased surface area for more absorption of nutrients (Sarikhan *et al*., 2010).

Manipulation of dietary ingredients in order to dilute the energy content of diet in broiler chickens

Feed intake restrictions have been interesting for broiler chickens producers in order to reduce abdominal fat deposition (Newcombe and Summers, 1985). Procedures to restrict

nutrient intake include intermittent lighting, limited feed accessibility and adding dietary diluents to diets (Newcombe and Summers, 1985). Newcombe and Summers, (1985) also reported that restriction of feed intake by limited feed accessibility led to a reduction of body weight and increased feed conversion ratio in broiler chickens. In addition, feed intake restrictions and realimentation in broiler chickens led to an increase in the energy requirement of the birds in order to compensate for the lack of energy during the restriction period (Leeson and Zubair, 1997). An increased energy requirement resulted in an increased growth rate of birds which is associated with increased carcass fat and therefore these birds may not be commercially optimal (Leeson and Zubair, 1997).

A study by Enting *et al*. (2007) showed that feed intake restrictions in broiler breeders may be associated with abnormal activities such as stereotypic object pecking, hyperactivity and increased feed intake motivation. The feed restrictions may cause chronic stress and hunger feelings and in consequence suppressed animal welfare (Hocking 2006; Enting *et al*., 2007). Reducing the nutrient intake by adding fibrous diluents in the diet may be recommended in order to facilitate a qualitative feed restriction rather than a quantitative feed restriction. Furthermore, Picard *et al*. (1999) suggested that broiler chickens could accustom themselves comfortably to diets diluted with fiber in the course of the finishing period. In addition, Picard *et al*. (1999) indicated that fiber diluted feed at the starter period may be beneficial for broiler chickens due to the stimulatory effect of the fiber on digestive tract. Enting *et al*. (2007) claimed that dilution of the diet with low energy feedstuffs such as oat hull may decrease chronic stress and hunger feelings and also suggested that 15% to 30% oat hull could reduce stereotypic behavior in broiler breeders. The experiment by Leeson and Zobair (1997) showed that birds fed a diet diluted with 50% oat hull showed higher metabolizable energy values than expected. This result indicated either those birds are able to acquire some nutrients from the oat hulls or that oat hulls dilution could influence general availability of nutrients in the diet (Leeson and Zobair, 1997).

Objective

The objective of the present experiment was to evaluate the effects of oat hulls on performance, carcass yield and gut development of broiler chickens. In addition, this study was designed to determine what level of oat hulls is optimal for performance carcass yield and gut development in broiler chickens having access to wood shavings as fibrous litter. It was hypothesized that inclusions of oat hull in the diet would improve gut development and performance in broiler chickens.

Materials and methods

Chickens, diets and experimental design

Two hundred one-day old Ross 308 male broiler chickens from the female parent stock line were acquired from a commercial hatchery in Sweden. The chickens were kept under treatment for 35 days. The chickens were randomly placed in 25 pre-disinfected pens at the

Swedish University of Agriculture Research Center Funbo-Lövsta, Uppsala, upon approval by the Uppsala local Ethics Committee. All cages were equipped with nipple drinkers, a feed plate for ground feed, wood shavings as litter substrate and a circular feed bin for pellet feed. Temperature and humidity were set according to the Ross manual. The chickens were fed *ad lib* and had free access to water during the experimental period. Each of the dietary treatments (including 0, 2, 4, 6 and 8% oat hulls on the expense of wheat) was offered to 5 pens, and each pen was defined as a replicate. The experimental diets are shown in Table 1. Birds were fed with experimental ground feed until the third day of the trial and they had access to pelleted feed from the start. On the third day of the trial all feed plates were removed from the pens. Until the third day of the experiment, dead birds were replaced (dead birds were not weighed) by extra birds which had been fed a control diet (0% oat hulls). From day four to the end of the trial, dead birds were removed and weighed but not replaced. Chickens in each pen were weighed together every week and any residual feed was also weighed weekly.

Table 1. Ingredient and nutrient composition of the experimental diets

	Oat hull %					
	0	2	4	6	8	
Wheat	68	66	64	62	60	
Soybean meal	25	25	25	25	25	
Soya oil	2.5	2.5	2.5	2.5	2.5	
Oat hulls	0	2	4	6	8	
Calciumcarbonate	1.6	1.6	1.6	1.6	1.6	
Monocalciumphosphate	1.5	1.5	1.5	1.5	1.5	
Salt	0.35	0.35	0.35	0.35	0.35	
DL-methionine	0.2	0.2	0.2	0.2	0.2	
L-lysine-HCl	0.4	0.4	0.4	0.4	0.4	
L-threonine	0.25	0.25	0.25	0.25	0.25	
Vitamin-mineral premix	0.25	0.25	0.25	0.25	0.25	
Calculated contents (g/kg dry matter)						Oat hull*
Dry matter	877	815	817	892	882	923
Ash	60	60	58	60	60	50
Crude protein	220	216	216	216	214	24
Fat	47	46	45	45	44	4
Lysine	135	13.4	13.3	13.2	13.3	-
Methionine	4.8	4.8	4.8	4.8	4.7	-
Threonine	9.7	9.7	9.7	9.5	9.9	-
Cystine	3.7	3.7	3.6	3.6	3.5	-
Starch	452	451	433	411	429	-
Crude fibre	3.1	4.1	4.5	5.1	5.3	325
Ca	10.42	10.76	10.51	9.51	10.18	0.82
P	7.80	8.36	8.46	7.83	7.47	0.72
Mg	2.14	2.21	2.13	1.99	2.02	0.52
K	7.61	8.03	7.62	7.57	7.55	3.31
S	2.21	2.23	2.17	2.08	2.10	0.37

DL-methionine, *L*-lysine and *L*-thereonine are synthetic amino acids.
* Chemical analysis of oat hull.

Volumetric determination of water holding capacity of feed

All feeds were ground (1 mm sieve, Cyclotec 1093) and on the following day 5 samples from each of the 5 experimental feeds (approximately 1 gram) were poured into volumetric plastic round bottom tubes (7 ml). The volume of each sample in the tubes was set to be 1.5 ml and after that 10 ml of tap water was added and the contents of the tubes were stirred by a small metal spoon. Stirring was repeated thrice in 20 minutes. Afterwards, the tubes were left standing for 2 hours. The increase of volume of each tube was estimated.

Gravimetric determination of water holding capacity (WHC) of feed and ileal digesta

Approximately 0.075 gram ground feed from each diet was poured into pre-weighed Eppendorf tubes. Approximately 1 ml of water was added into each tube and the tube contents were homogenized with a Vortex mixer for a few minutes. All tubes were centrifuged thrice at 13,000 *g* for 10 min, discarding the supernatant in each centrifugation. Then the tubes were weighed. In a similar manner, the water holding capacity of ileal digesta was determined gravimetrically, with the only difference being the amount of sample used (approx. 0.035g). Each determination was replicated five times. Approximate water holding capacity (WHC) was calculated by the equation below (Ramanzin *et al*., 1994).

$$WHC = \frac{\text{(Eppendorf weight + sediment weight)-(Eppendorf weight + sample weight)}}{\text{Sample Weight}} * 100$$

Determination of pH and dry matter of faeces

On day 28, wet faeces were collected by putting plastic covers under the pens and by removing the litter covered floor of all pens. Faeces collection took nearly half a day. Faeces from each pen were pooled and placed in separate plastic zip bags and stored in a freezer at -20°C. On the following day, samples were thawed at room temperature. Approximately 4 g of wet faeces from each sample was poured in volumetric tubes and 10 ml distilled water was added into each tube. The contents of the tubes were homogenized by a mixer (Vortex mixer) for 2 minutes. After blending the contents, the samples were centrifuged (WIFUG, Stockholm, Sweden) at 3,000 *g* for 3 min. The pH of supernatant of each sample was measured by pH-Meter (METROHM 654). Other samples of pre-weighed wet faeces were transferred into pre-weighed metal containers. The containers were placed in the oven at 105°C over night. In the following day the containers were weighed and recorded individually. Dry matter percentage (DM %) was calculated by the following formula:

$$DM\% = \frac{\text{Sample Weight after drying}}{\text{Sample Weight before drying}} * 100$$

Measurement of particle size distribution in feed by wet sieving

The feed particle size distribution for all experimental feeds was measured by a wet sieving method (van Krimpen *et al*., 2008). This procedure involved 8 metal sieves with different mesh sizes (2, 1, 0.8, 0.63, 0.5, 0.315, 0.25, and 0.16 mm). The pre-weighed sieves were placed on top of each other in pore size order from largest to finest mesh. Then, 100 g pelleted feed was soaked in 1.5 l warm tap water (40-50 °C) for 2 hrs and the soaked feed was poured onto the top sieve. The sample was rinsed by 2 l warm tap water (40-50°C), sprinkled over the top sieve in order to assist the particles to pass through the sieves. The sieves were then set to drain for a while. Finally, all sieves were placed in a drying chamber at 60°C overnight and weighed individually on the following day. The particle size fractions were calculated by subtracting empty sieve weights from the weights of sieves after fractionation. The finest fraction was calculated by subtracting the sum of weights of sieves between 2 and 0.16 mm mesh size from the total amount of feed used in the procedure. Feed particle distribution is summarized in Table 2, below.

Table 2. Particle size distribution of experimental feed

	Oat hull %				
Fraction size	0	2	4	6	8
>2 mm	0.4	0.6	0.6	0.4	0.8
2 mm > fraction > 1 mm	41.6	42.3	35.9	40.4	41.6
1 mm > fraction > 0.8 mm	2.1	1.7	3.9	4	1.5
0.8 mm > fraction > 0.63 mm	1.9	1.8	4.3	3.3	1.8
0.63 mm > fraction > 0.5 mm	1.3	1.4	1.3	2.5	1.2
0.5 mm > fraction > 0.315 mm	1.6	1.9	3.5	4.2	11.6
0.315 mm > fraction > 0.25 mm	0.7	0.8	1.0	1.9	0.5
0.25 mm > fraction > 0.16 mm	2.7	1.3	3.0	1.5	1.1
< 0.16 mm	47.7	48.2	46.5	41.8	39.9

Dissection and measurement of weight and length of gastrointestinal tract and digesta pH in GIT segments

On day 35 one bird from each pen was randomly selected, killed, weighed and dissected. The chickens were killed by cervical dislocation. The spleen and liver were dissected and weighed. The GIT was cut into gross morphological segments: gizzard+proventriculus (G+P), duodenum, jejunum, ileum, ceca and colon and the lengths (not G+P) and weights (with digesta) of the segments were recorded. The crop with digesta was weighed as well. Afterwards, the digesta within the different segments was collected and the GIT segments were rinsed in tap water, dried separately with paper towels and weighed again without digesta. In addition, one of the ceca was sent to the Swedish National Veterinary Institute (SVA) for clostridia enumeration. The collected digesta was put in separate Falcon tubes and placed in a freezer at -20°C. Next day, a small amount of digesta was poured into a plastic round bottom tube and approximately 10 ml distilled water was added. The samples were

homogenized for 2 min and centrifuged at 3,000 *g* for 3 min, and the pH of the supernatant was measured.

Liver and carcass preparation for fat (ether extract) analysis

The livers were separated from the body and weighed at the dissection on day 35. The livers were frozen (-20°C) and when thawed, they were cut and mashed and placed in Petri dishes. After that, these Petri dishes were placed in the freezer at -80°C prior to freeze-drying. The freeze dried samples were ground in a coffee mill and sent to the laboratory at Kungängen for fat (ether extract) analysis. On day 36, the chickens were weighed and sent to the slaughter house. Following stunning, debleeding and defeathering, one chicken from each pen was randomly selected for carcass fat (ether extract) determination. The carcasses were placed in the freezer at -20°C for a few days. Afterwards, the chickens were minced separately in an electrical meat grinder and approximately 100 g of homogenized representative sample was poured into a Petri dish. The Petri dishes were placed in the freezer at -80°C for subsequent freeze-drying. The fat (ether extract) content of carcass was determined similar to liver fat (ether extract) analysis.

Feed conversion ratio calculation

Feed intakes (FI) and body weights (BW) were recorded weekly; feed conversion ratio (FCR) was calculated as feed intake (g)/ weight gain (g). Feed intake and weight gain were calculated on pen basis and presented on average bird basis. Mortality was corrected for by estimating the feed intake of the dead chickens, according to the Ross manual. Correspondingly, the live weight and feed intake of the dissected birds on day 35 were corrected for. An example is shown in appendix 1.

Statistical analysis

All data was submitted to the ANOVA procedure for completely randomized designs using the GLM model (SAS, 1998). The inclusions of oat hulls (OH) in the feed were considered a fixed effect. Differences were considered significant at $P < 0.05$ and differences were considered trends when $0.05 \leq P \leq 0.10$. When significant main effects were identified, differences between means were separated by the LSD procedure.

Results

Effects of oat hull on gastrointestinal segments (length, weight and pH) and cecal clostridium count

There were no effects of oat hull (OH) inclusions on the mean live weight and proportional weight of the liver, spleen, crop, duodenum, cecum and colon GIT relative to the live weight when the digesta remained; see Table 3. The relative weight of the GIT with digesta tended to increase with OH inclusion in the diet, except for birds fed 4% OH; Table 3. There was an

effect of OH inclusions on the relative weight of ileum with digesta ($P < 0.004$; Table 3). However, there was no main difference in average ileal weight of chickens fed 4% OH, compared to the average ileal weight of control group (0% OH); see Table 3. The relative jejunal weight with digesta was affected by OH inclusion in the diet ($P < 0.04$; see Table 3). However, only 8% inclusion of OH significantly increased the relative weight of jejunum with digesta in comparison with the control group (0%) and 4% OH inclusion; Table 3.

Table 3. Effect of inclusions of oat hull in feed on weight of liver, spleen and the GIT (including digesta) relative to live weight on day 35

	Oat hull %*						
Variable (% of LW)	0	2	4	6	8	SEM	P > F
Liver	2.34	2.24	2.28	2.19	2.03	0.0013	0.50
Spleen	0.11	0.12	0.10	0.13	0.10	0.0002	0.58
Crop	0.54	0.38	0.42	0.44	0.44	0.0004	0.96
GIT	7.32	8.16	7.34	8.58	9.04	0.0046	0.06
**G + P	1.64	1.40	1.76	1.32	1.82	0.0017	0.20
Duodenum	0.90	0.92	0.82	0.92	0.94	0.0005	0.46
Ileum	1.16^{b}	1.64^{a}	1.14^{b}	1.54^{a}	1.70^{a}	0.0012	0.004
Jejunum	1.82^{b}	2.00^{ab}	1.64^{b}	2.02^{ab}	2.26^{a}	0.0013	0.04
Cecum	0.34	0.34	0.39	0.38	0.42	0.0004	0.66
Colon	0.25	0.26	0.23	0.32	0.27	0.0015	0.70

*Different individual superscripts within rows among columns differ significantly ($P < 0.05$). **Gizzard + Proventriclus. SEM: standard error of the mean.

When digesta contents were removed from the different segments of the gastrointestinal tract, there were no effects of OH inclusion on relative weight of the gastrointestinal segments except for the ileum ($P < 0.0004$; Table 4). The relative weight of ileum was heaviest in chickens fed 2% OH. Interestingly, the relative weight of ileum of chickens fed 4% OH in their diet had numerically the lowest weight of all treatments; see Table 4 and Table 12. Also, the relative weight of empty gizzard with proventriculus tended to increase in response to OH inclusion; Table 4. Moreover, the relative weight of empty jejuna tended to be affected when 2 and 6% OH were added into the diet; Table 4.

Table 4. Effect of inclusions of oat hull in feed on the weight of GIT (excluding digesta) relative to live weight on day 35

	Oat hull %*						
Variable (% of LW)	0	2	4	6	8	SEM	P > F
Crop	0.20	0.21	0.28	0.30	0.24	0.0003	0.17
G + P	1.12	1.15	1.34	1.16	1.29	0.0006	0.09
Duodenum	0.70	0.81	0.62	0.74	0.74	0.0005	0.17
Ileum	0.87^{b}	1.00^{a}	0.75^{c}	0.89^{b}	0.87^{b}	0.0003	0.0004
Jejunum	1.09	1.21	1.00	1.19	1.01	0.0006	0.09
Cecum	0.14	0.15	0.17	0.16	0.16	0.0001	0.53
Colon	0.13	0.14	0.15	0.16	0.15	0.0001	0.21

*Different individual superscripts within rows among columns differ significantly ($P < 0.05$). **Gizzard + Proventriclus. SEM: standard error of the mean.

In terms of intestinal length, OH feeding in different inclusions did not have an effect, except for the ileum which was elongated by OH inclusion in the diet (P < 0.03; Table 5). Average ileal length increased in chickens fed higher inclusions of OH such as 6 and 8% compared to chickens fed 0 and 4% OH inclusions; Table 5. In addition the average colon length tended to increase in response to 6 and 8% OH; Table 5.

Table 5. Effect of inclusions of oat hull in feed on length GIT on day 35

	Oat hull %*						
Variable (cm)	0	2	4	6	8	SEM	P > F
Duodenum	29	31	29	31	31	1.52	0.55
Jejunum	63	66	63	73	67	3.94	0.38
Ileum	63[b]	67[ab]	63[b]	73[a]	76[a]	3.30	0.03
Cecum	17	17	15	16	17	1.05	0.45
Colon	7	7	6	8	8	0.51	0.09

*Different individual superscripts within rows among columns differ significantly (P < 0.05). SEM: standard error of the mean.

There were no effects of OH feeding on the pH of cecum, ileum, jejunum and gizzard. However, duodenal pH tended to increase in response to OH, see Table 6.

Table 6. Effect of inclusions of oat hull in feed on GIT pH on day 35

	Oat hull %*						
Variable	0	2	4	6	8	SEM	P > F
Ceca	6.8	6.3	6.3	6.4	6.7	0.24	0.35
Ileum	6.6	6.9	8.1	7.1	7.3	0.42	0.18
Jejunum	5.9	6.0	6.3	6.1	5.8	0.13	0.32
Duodenum	5.7	6.0	6.2	6.0	5.8	0.10	0.05
G + P	5.0	4.7	4.4	4.9	4.7	0.27	0.49

*Different individual superscripts within rows among columns differ significantly (P < 0.05). **Gizzard + Proventriclus. SEM: standard error of the mean.

There were no significant effects of different inclusions of OH in the diet on cecal clostridium count (P < 0.99; see Table 7).

Table 7. Effect of oat hull inclusions in feed on cecal Clostridium perfringens count

	Oat hull %*						
Variable	0	2	4	6	8	SEM	P > F
Clostridium peringens CFU/g	4.42	4.80	4.56	4.46	4.44	0.65	0.99

*Different individual superscripts within rows among columns differ significantly (P < 0.05). SEM: standard error of the mean. CFU/g: colony forming units per gram cecal digesta.

Effects of oat hull on gravimetric determination of water holding capacity (WHC) of feed and ileal digesta and volumetric determination of water holding capacity of feeds

Gravimetric water holding capacity (WHC) of ground feed was affected by different OH inclusions ($P < 0.003$; Table 8). As seen in table 8, the gravimetric WHC of feed was significantly increased by including 6 and 8% OH in the feed. However, 2 and 4% OH inclusion did not change the gravimetric WHC of feed. In contrast, the gravimetric WHC of ileal digesta was not affected by different OH inclusions; see Table 8.

Table 8. Effects of oat hull inclusions in feed on gravimetric determination of water holding capacity (WHC) of feed and ileal digesta

	Oat hull %*						
Variable (%)	0	2	4	6	8	SEM	P > F
Feed WHC *g*	111[b]	106[b]	111[b]	117[a]	117[a]	1.98	0.003
Ileal digesta WHC *g*	696	631	671	751	798	46.35	0.16

*Different individual superscripts within rows among columns differ significantly ($P < 0.05$). SEM: standard error of the mean. *g*: Gravimetric.

Volumetric WHC of ground feed was affected by OH inclusion ($P < 0001$; Table 9). The results indicate that only 4 and 8% OH significantly increased volumetric WHC of ground feed. However, the volumetric WHC of ground feed containing 2 and 6% OH was not different from the control diet; see Table 9.

Table 9. Effect of oat hull inclusions in feed on volumetric determination of water holding capacity (WHC) of feeds

	Oat hull %*						
Variable	0	2	4	6	8	SEM	P > F
Feed WHC *v*	113[b]	109[b]	128[a]	111[b]	128[a]	2.11	<0.0001

*Different individual superscripts within rows among columns differ significantly ($P < 0.05$). SEM: standard error of the mean. *v:* Volumetric.

Faecal dry matter and pH and fat percentage of liver and carcass

There were no effects of OH inclusions on mean faecal DM % and pH (Table 10), and including OH had no significant effect on the fat percentage of liver and carcass, see Table 11.

Table 10. Effect of oat hull inclusions in feed on faecal pH and dry matter (DM)

	Oat hull %*						
Variable	0	2	4	6	8	SEM	P > F
Faecal DM, %	22	20	23	23	23	1.12	0.31
Faecal pH	5.8	5.5	5.8	5.7	5.9	0.11	0.17

*Different individual superscripts within rows among columns differ significantly ($P < 0.05$). SEM: standard error of the mean.

Table 11. Effect of oat hull inclusions in feed on the fat content of liver and carcass

	Oat hull %*						
Variable (%)	0	2	4	6	8	SEM	P > F
Liver fat	20	20	21	17	15	3.66	0.77
Carcass fat	36	37	37	36	36	1.42	0.97

*Different individual superscripts within rows among columns differ significantly (P < 0.05). SEM: standard error of the mean.

Effect of OH on carcass weight, live weight, mortality, WG, FI and FCR

Carcass weight, live weight and carcass weight relative to live weight was not affected by different levels of OH in the diet; see Table 12. In terms of chicken performance, feed intake (FI) and feed conversion ratio (FCR) were affected by OH inclusions P < 0.01 and P < 0.03 respectively; see Table 13. However, only 4 and 6% OH inclusions in the feed significantly increased FI compare to control diet, and there were no main differences in the FI of chickens fed 2 and 8% OH in their diet compared to chickens fed 0% OH; Table 13. FCR was significantly increased when the chickens were fed 6% OH inclusion compared to 0, 2 and 8% OH inclusions; Table 13. However, weight gain (WG) was not affected by different inclusions of OH; Table 13.

Table 12. Effect of oat hull inclusions in feed on carcass, live and carcass relative live weight

	Oat hull %*						
Variable	0	2	4	6	8	SEM	P > F
Carcass weight g	1554	1576	1626	1618	1621	35.46	0.52
Live weight g	2200	2177	2224	2320	2297	92.52	0.77
Carcass/live g/g	0.71	0.72	0.73	0.70	0.71	0.02	0.83

*Different individual superscripts within rows among columns differ significantly (P < 0.05). SEM: standard error of the mean.

Table13. Effect of oat hull inclusions in feed on weight gain (WG), feed intake (FI) and feed conversion ratio (FCR) of chickens

	Oat hull %*						
Variable	0	2	4	6	8	SEM	P > F
FI g	3530^{c}	3645^{cb}	3861^{ab}	3961^{a}	3722^{abc}	83.99	0.01
WG g	2072	2136	2183	2187	2167	45.32	0.38
FCR g/g	1.71^{b}	1.70^{b}	1.77^{ab}	1.81^{a}	1.72^{b}	0.03	0.03

*Different individual superscripts within rows among columns differ significantly (P < 0.05). SEM: standard error of the mean.

Discussion

In this experiment, inclusion of oat hull (OH) in different levels increased feed intake (FI) without affecting the weight gain (WG). However, the increase in FI was only significant for 4 and 6% of oat hull (OH) inclusion compared to control. This finding confirms earlier work by Hetland and Svihus (2001) who observed that an inclusion of 4% oat hull in the diet increased feed intake without affecting weight gain in broiler chickens. According to our

findings in this trial, including 8% OH in the diet did not significantly increase FI. This should be seen in the context that the 8% OH diet contained 8% less wheat, and consequently less AME, than did 0% OH. As chickens normally compensate for lower AME values by increasing their FI, the chickens fed 8% OH probably utilized their feed better than chickens fed the control diet. Wallis *et al*. (1985) concluded that feed intake was increased by supplementing the wheat based diet with 10% oat hull. In contrast, Sarikhan *et al*., (2010) investigated that insoluble fiber did not affect feed intake in broiler chickens. In terms of weight gain, Sarikhan *et al*. (2010) reported that WG was increased by the inclusion of insoluble fiber in the broilers' diet. Also, 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. However, in this current study WG was not affected by different inclusions of the different OH inclusions such as 2, 4, 6 and 8%. Broilers may compensate for decreased nutrient concentration associated with insoluble fiber inclusion by increasing feed intake (Mourao *et al*., 2008). Also González-Alverado *et al*. (2010) reported that oat hull contains higher lignin and cellulose thus, increased level of insoluble fiber resulted in a higher passage of ingesta through the distal part of the GIT which leads to increased feed intake. A feed intake increment might be associated with an increased gut volume (Hetland and Svihus, 2001). Interestingly, in this experiment the chickens fed 2% OH inclusion had almost the same feed intake as chicken fed control diet (0% OH). This finding might be in agreement with González-Alverado *et al*. (2010) who reported that a moderate level of insoluble fiber, i.e. 3%, in broiler chickens feed had less effect on FI compared to 5% inclusion of insoluble fiber. However, Pettersoon and Razdan (1993) reported that the chickens fed lowest inclusion of sugar-beet pulp (2.3%) as a source of insoluble fiber had higher FI in comparison to 4.6 and 9.2%. Therefore, González-Alverado *et al*. (2010) suggested that effects of dietary fiber on broiler chicken performance could be altered by type of fiber. In the current study feed conversion ratio (FCR) was significantly increased by 6% OH inclusion compared to control diet. However, Sarikhan *et al*. (2010) observed that dietary insoluble fiber improved FCR in broiler chickens. Khempaka *et al*. (2009) reported that a high inclusion of fiber (up to 12-16%) could reduce the body weight due to depressed feed intake following increased diet bulkiness and limited digestive tract capacity in chickens from day 14 to day 35. Besides, Mourao *et al*. (2008) demonstrated that inclusions of 5 and 10% of insoluble fiber increased FCR and FI as well as reduced WG. According to our findings, insoluble fiber inclusion up to 8% in broiler chickens diet did not affect WG. From economic point of view, a high feed conversion ratio may lead to financial losses for producers.

Dissection data in the current experiment indicate that 8% OH inclusion significantly increased ileal and jejunal weight with digesta. Also gastrointestinal weight with digesta tended to increase when the diet supplemented with 8% OH. Moreover, inclusion of 2 and 6% OH significantly increased ileal weight with digesta, and the empty ileal weight was increased by 2% OH inclusion. In addition, 4% OH inclusion tended to increase empty gizzard with proventriclus. Furthermore, Ileal length was significantly increased by 6 and 8% OH inclusions compared to 2 and 4% OH inclusions. Also colon length tended to increase in response to OH inclusions of 6 and 8%. Borin *et al*. (2006) suggested that greater caeca and colon volume in broilers might increase the digestive capacity, following a high fiber content

in the diet. The results in the present study corresponds with the study by Khempaka *et al*. (2009) which stated that ileal and jejunal length increased by insoluble fiber inclusion in broiler diets. In contrast, Rogel *et al*. (1987a) observed that lengths and weights of segments of the small intestine of broilers decreased when the birds were fed 10% oat hulls. Taylor and Jones (2004) reported that a gizzard enlargement may lead to a reduction of the relative weight of the small intestine, which in turn may reflect an adaptation of the gut to an increased availability of nutrients. Others have also observed accumulations of gizzard contents, acidification of ingesta in the gizzard and gizzard enlargement when feeding insoluble fibers (González *et al*., 2007). This result was supported by Rogel *et al*. (1987a) and Riddell (1976) who reported gizzard enlargement due to oat hull inclusion in the feed. In the current experiment fiber particles were long (> 1 mm) as determined by wet sieving. Long fibers have previously been shown more effective to stimulate and enlarge the gizzard (Rogel *et al*., 1987a) and make it more muscular due to the increased resistance when grinding the feed (Jiménez-Moreno *et al*., 2009). A more muscular and enlarged gizzard can possibly improve digestion since the feed is retained for a longer time in the upper digestive tract (proventriculus and gizzard). This allows digestive enzymes to be active and consequently the digestion is more efficient (Jones and Taylor 2001). Mateos *et al*. (2002) reported that large particle size induced peristalsis movement more than small particle sizes. Thus large fiber particles increase gut motility and retrograde movement inside the gastrointestinal tract, which may benefit nutrient utilization. In this trial the gravimetric water holding capacity of ground feed increased when 6 and 8% OH were included in the diet. Also, the volumetric water holding capacity of ground feed was increased by 4 and 8% OH inclusions. This finding is in contrary to Jiménez-Moreno *et al*. (2009) who stated that oat hulls have low water holding capacity due to their lignifications. This result was in agreement with Kirwan *et al*. (1974). It is believed that insoluble fiber increases the water holding capacity of digesta in gut (Montagne *et al*., 2003) but in our experiment the water holding capacity of ileal digesta was not affected by different OH levels.

In terms of carcass weight and carcass weight relative to live weight, Shahin and Abdelazim (2005) demonstrated that high fiber in broilers' diet (8% inclusion) suppressed carcass weight compared to low fiber 4% inclusion. Mourao *et al*. (2008) indicated that broilers fed oat hulls had lower carcass weights and carcass relative live weights due to a more developed gastrointestinal tract. However our results were not in agreement with their studies. In the present study, carcass weights and carcass weights relative to live weight were not influenced by oat hull inclusions in the broiler diets. Besides, Pettersoon and Razdan (1993) reported that 2.3% sugar-beet pulp (insoluble fiber) supplementation in the broiler diet increased live weight. Regarding carcass and liver fat contents, in this current trial oat hull inclusions did not affect the fat content of carcass and liver. Shahin and Abdelazim (2006), however, showed that the fat content of carcass was reduced when birds were fed on a high fiber inclusion diet. In addition, Sarikhan *et al*. (2010) reported that the abdominal fat pat weight increased when the fiber content of the diet was low. Abdominal, carcass and overall body fat were reduced by high fiber inclusion in the diet (Shahin and Abdelazim 2006). Furthermore, Akiba and Matsumoto (1982) showed that fiber may reduce liver lipid deposition and plasma lipid content in chickens fed *ad libitum*. Akiba and Matsumoto (1978) reported that plasma lipid

was suppressed by cellulose inclusion in the diet and they also found that inclusion of oat hull led to a negligible reduction in liver lipid in chickens. However, these findings did not reveal whether the lipid reduction in the liver was caused by fiber content or reduced energy intake (Akiba and Matsumoto 1978). In the current study, liver fat content was not affected considerably by oat hull inclusion.

Jiménez-Moreno *et al*. (2009a) showed that pH values of different segments of the gastrointestinal tract, such as the gizzard, were affected by 3% OH inclusion in the diet. However, our results could not support this finding except for the duodenal pH value, which tended to increase by 4% OH inclusion. In another study, the pH value of the gizzard was reduced by oat hull inclusion owing to stimulation of hydrochloric acid (HCl) production in the proventriculus (Jiménez-Moreno *et al*., 2009). Our results did not show any effects of OH inclusions on *Clostridium perfringens* counts in caecum. Therefore our results could not support the hypothesis by Svihus *et al*. (2002) who suggested that a high passage rate of digesta in the gut may decrease the detrimental microorganism's proliferation such as *Clostridium perfringens*.

By day 35, a high amount of wood shaving particles was observed in the gizzard of one chicken which had access to 4% OH in its diet. This chicken also had leg problems and therefore a lower live weight (1678g) was observed in this chicken. These observations hypothetically indicated that this chicken consumed wood shavings from the litter in order to compensate for the lack of feed. However, the amount of wood shavings was not registered in the gizzard of other chickens.

Conclusions

In the current study feed intake and feed conversion ratio was significantly increased by inclusion of 6% oat hulls in the broiler chickens diet. Also 4% OH inclusion increased feed intake. However, 8% OH inclusion did not significantly affect feed intake or feed conversion ratio. The chickens fed 2% OH had nearly the same performance as the control fed chickens. Therefore, according to this study, a low inclusion of OH may not affect broiler chicken performance, but a high inclusion of OH may increase feed intake. On the other hand, high inclusions of OH tended to increase the weight of empty gizzard, which is the regulatory organ in the GIT of chickens. In addition, higher inclusions of OH increased the weight of digesta in the jejunum and ileum. Since there was no negative effects of oat hull inclusion on e.g. weight gain, oat hull supplementation may be recommendable to broiler chickens. The increased feed intake seen in this trial might be due to the developed gut or/and lower energy content in the diet. In addition, the chickens which had access to oat hull inclusion in the diet needed to eat more feed than the control group in order to compensate for the lower energy values in their diets. The optimal level of OH inclusion is still uncertain and further studies are necessary to determine the optimum level and contribution of this feedstuff to broiler chicken performance and gut development.

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Appendix 1. Male performance (Ross manual)

Day	Bodyweight (g)	Daily gain (g)	Av. Daily gain/week (g)	Daily intake (g)	Cum. Intake (g)	FCR
0	42					
1	56	14				
2	71	15				
3	89	18				
4	109	20				
5	131	22				
6	156	25				
7	184	28	20.29		162	0.880
8	215	31		39	201	0.935
9	250	35		44	245	0.980
10	287	37		49	294	1.024
11	328	41		54	348	1.061
12	372	44		60	408	1.097
13	420	48		64	472	1.124
14	471	51	41.00	70	542	1.151
15	525	54		77	619	1.179
16	583	58		82	701	1.202
17	644	61		88	789	1.225
18	708	64		94	883	1.247
19	776	68		100	983	1.267
20	846	70		107	1090	1.288
21	920	74	64.14	113	1203	1.308
22	996	76		120	1323	1.328
23	1075	79		126	1449	1.348
24	1157	82		132	1581	1.366
25	1241	84		138	1719	1.385
26	1327	86		144	1863	1.404
27	1415	88	83.57	150	2013	1.423
28	1505	90		157	2170	1.442
29	1597	92		162	2332	1.460
30	1690	93		167	2499	1.479
31	1785	95		173	2672	1.497
32	1880	95		179	2851	1.516
33	1977	97		183	3034	1.535
34	2075	98		188	3222	1.553
35	2173	98	95.43	193	3415	1.572

* Example: if mortality occurred and the weight of the dead chicken was 480g, then 480g was subtracted from the pen weight. Feed intake by the dead chicken was estimated as follows:

480/471*542 = 552g
Thus, 552 g is the amount of feed which a chicken is estimated to eat in order to reach a weight of 480 g. This amount of feed was consequently subtracted from the feed intake of the group.

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