ABSTRACT

XU, YI. Interaction of Dietary Coarse Corn with Litter Conditions on Broiler Live Performance and Gastrointestinal Tract Function. (Under the direction of Dr. Charles R. Stark and Dr. Peter R. Ferket.)

The successful application of whole wheat in the EU indicated that dietary structural material, such as coarsely ground corn (CC), could be included in US broiler diets to improve live performance. The main objective of this study was to evaluate the effects of broiler feed structure and litter conditions on broiler live performance, nutrient digestibility, and gastrointestinal tract (GIT) development and function in different scenarios. It was hypothesized that dietary CC inclusion and new litter condition may significantly improve broiler live performance and nutrient digestibility, as well as influence the functional development and motility of the broiler GIT. We also hypothesized that dietary CC would decrease feed cost and litter nitrogen, moisture, and ammonia emission. Our objective was to understand and quantify the effects of dietary structural material inclusion and litter management on broiler live performance and development of different GIT sections by measuring the relevant physical, morphological, and histological parameters of the GIT during broiler feeding trials.

Therefore, the focus of this dissertation was: 1) to study the impact of corn particle size distribution with litter conditions on broiler live performance and nutrient digestibility; 2) to investigate the influence of corn particle size distribution and litter condition on broiler GIT development and function by measuring the relevant physical, morphological, and histological parameters; 3) to investigate the effects of corn particle size distribution on broiler litter nitrogen, moisture, and ammonia emission; and 4) to quantify and develop a feeding regime of dietary corn particle size distribution that decreased feed cost while optimizing broiler live performance and GIT development and function.

The dissertation research carried out 2 cages studies, 4 floor studies, and 1 grinding cost analysis study. Experiment 1 evaluated the effects of six dietary CC inclusion levels in two feed form on broiler live performance, BW uniformity, relative gizzard weight, fecal nitrogen, and particle size preference behaviors of broiler raised in cages from 0 to 14 d of age. Experiment 2 and 3 investigated the effects of gender, litter conditions, and dietary CC inclusion on live performance, gizzard and proventriculus development, litter characteristics, and colon bacterial profiles of broiler raised on a litter-covered floor from 0 to 49 d of age. Experiment 4 was a 45 d cage study that investigated the effects of three dietary CC inclusions on broiler live performance, GIT development, apparent ileal digestibility (AID) of energy and nitrogen, jejunum digesta particle size distribution, and feed retention time. Experiment 5 evaluated the effects of two dietary CC inclusions and two litter conditions on broiler live performance, litter characteristics, GIT development, apparent ileal digestibility of energy and nitrogen, and intestinal morphology. Experiment 6 investigated the effects of two dietary CC inclusion and three different floor types on broiler live performance, litter characteristics, GIT development, apparent ileal digestibility of energy and nitrogen, intestinal morphology, and ammonia emission. Corn grinding cost by hammermill and roller mill was also compared.

In conclusion, dietary CC inclusion decreased feed cost, improved nitrogen and energy digestibility, altered GIT bacterial population, improved feed efficiency, and reduced litter ammonia emission through the modulation of GIT function as evidenced by increased gizzard weight, greater digesta retention time, decreased digesta pH, modified intestinal morphology structure, and decreased litter moisture and nitrogen. We also found that the effects of dietary CC inclusion could confound pellet quality, while new litter had only a marginal benefit on broiler live performance. Particle size distribution was found to be more important than the geometric mean diameter by mass (dgw) with regard to the paradoxical role of particle size on poultry feed manufacturing and nutrition.

Interaction of Dietary Coarse Corn with Litter Conditions on Broiler Live Performance and Gastrointestinal Tract Function

by
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DEDICATION

To my family and those whom I care for.

BIOGRAPHY

Yi Xu was born on May 20, 1980 in Lingbao, Henan, China. He received his elementary, secondary, and high school education in Lingbao. In 1997, Yi began his undergraduate studies at the Zhengzhou Grain College (Presently Henan University of Technology) with a major in Feed Science. After receiving his Bachelor of Science degree in July 2001, Yi was admitted by Nanjing Agriculture University to study Animal Science with a concentration in Nutrition under the direction of Dr. Tian Wang and Dr. Yanmin Zhou. He completed his Master Degree in July 2004, and worked in China's feed industry for 6 years, including 3.5 years for the American Soybean Association in Beijing. Since August 2010, Yi was granted a research assistantship in the Prestage Department of Poultry Science at North Carolina State University in order to pursue a Doctor of Philosophy Degree in Poultry Science with an emphasis in feed processing and nutrition.

The author is marred to Rong Jin, and they have a daughter Ginger Jinsin Xu.

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I would like to thanks my parents, Mr. Jigang Xu and Mrs. Xiaoying Kang, and my sister Mrs. Jinru Xu, for the love only family could provide.

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AdjFCR	Adjusted feed conversion ratio, corrected for weight of mortality
BW	Body weight
C	Celsius
cm	Centimeter
d	Day
dgw	Geometric mean diameter by mass
FCR	Feed conversion ratio
g	Gram
GIT	Gastrointestinal tract
h	hour
kg	Kilogram
m	Meter
WN	Wire net floor
NL	New wood shavings litter
RL	Recycled old litter
sgw	Standard deviation of geometric mean particle size
wk	Week

CHAPTER 1

LITERATURE REVIEW

1. INTRODUCTION

The commercial poultry industry in the USA and other countries has undergone rapid structural change during the past few decades. It has evolved from fragmented, locally oriented businesses into a large-scale and highly efficient, often vertically integrated business, thereby establishing a single profit center and allowing for product quality control throughout the entire grow-out and processing chain. An integrator owns the breeder flock, hatchery, feed mill and processing plants in an area and is responsible for supplying growers (contract farmers) with chicks, feed, supervision, transportation (feed and chicks), and the processing and marketing of the final product. The contract grower is responsible for daily labor, facilities (house, feeders, etc.) and energy costs (electric, gas). Commercial broiler houses are about 600 feet in length and hold up to 30,000 broilers. These new, fully automated houses cost upwards of $300,000. A service technician (hired by the integrator) visits a contract farm periodically to ensure the health and proper management of birds. At the end of a grow-out (38 to 62 d), birds are caught, loaded onto a truck, and transported to the processing plant. Growers are paid by the pound of live weight (approximately $0.05/pound) and they may grow up to seven flocks of birds per year.

Different strategies have contributed to the improvement of broiler live performance. The introduction of modern intensive production methods, genetic improvement, development of knowledge regarding accurate nutrient requirements, computer-based feed manufacturing, and advanced health and biosecurity programs have resulted in a broiler chicken that reached market weight (approximately 5 pounds) in one-third less time (101 d *versus* 32 d) with a dramatic improvement in FCR (4.42 versus 1.47) (Havenstein et al., 1994; 2003). Meanwhile, the genetic potential for growth of the modern broiler chickens has continued to improve by 50 g each year. Therefore, the marketing age of broilers has decreased by an average of 0.75 d per year (Gunasekar, 2007).

These are many challenges that will influence the evolution of the poultry industry in coming decades. Pressures from increasing feed cost, pursuing better feed efficiency and live performance, animal welfare, food safety, and environmental impact relative to poultry production have been identified as major challenges to the poultry industry. While the poultry industry pursues higher production and efficiency, they continually strive towards better meat product quality at a lower costs of production. First, the poultry industry has faced increasing feed ingredient prices in competition with direct grain consumption by a strongly expanding global human population and with grain use for bio-fuel production. According to OECD-FAO (2010) estimates, feedstuff prices will remain higher than the historical average between 2010 and 2019, but lower than the peaks experienced in 2007 and 2008. Second, consumers have demanded more attention to animal welfare demonstrated by increasingly stringent legislative regulation. Indicators that will be used to measure animal welfare will be related to good feeding, good housing, good health status, and acceptable behavior (Lymbery, 2004). Improved house and environment management with innovative feeding practices will not only improve animal welfare and live performance, but will also decrease nutrient concentrations in litter and emissions to the environment. Third, from a food safety perspective, restrictions on antibiotic use as growth promoters have required nutritionists to change their paradigms with emphasis placed on improved gut function without antibiotic protection. The interaction between feed and gastrointestinal tract (GIT) health, function, bacteria, and immunity will be re-modulated without relying on therapeutic antibiotics. Fourth, to improve feed efficiency and to decrease nutrient excretion to environment, there has been an increased interest in modulation of GIT function by nutritionists, in effects to decrease feed cost through use of inexpensive but fibrous ingredients. Meanwhile, diets will have to be formulated more accurately without large safety margins, while using techniques to improve ingredient digestibility and nutrient absorption, as well as reduce the detrimental effects of anti-nutritional factors. Approaches that will allow flexibility in the use of feedstuff as well as reduce feed costs and environmental impacts will be developed.

The successful application of whole wheat in the EU demonstrated one promising means to solve these challenges to US poultry industry. The use of whole wheat has been shown to reduce input feed costs, grinding costs at the feed mill, and mortality and condemnations rates, and improve feed efficiency, flock health, live performance, profits, and feed mill capacity as whole wheat does not need grinding or pelleting. The unique interaction between whole wheat and poultry GIT development and function indicates that dietary structural material, such as coarse corn (CC) and dietary fiber, may be successfully applied in the US poultry production system in a similar manner.

Although the poultry industry has faced many challenges, further feed efficiency and growth improvements is expected to be gained through a better understanding and exploitation of factors within the GIT system that govern nutrient digestion and availability. The following review of the scientific literature is focused on the poultry GIT, and the interaction between feed processing and GIT development and function.

2. FUNCTIONS OF THE GASTROINTESTINAL TRACT OF POULTRY

Avian GIT morphology, digestive strategy, and metabolic capability are intimately intertwined during evolutionary adaptation to match the nutrient content and physical attributes of foods available in its natural habitat (Klasing, 1999). A better understanding of basic and unique anatomic and physiological features of the broiler GIT has become essential to developing an effective and economical nutritional and feeding strategy for modern broilers.

2.1 Basic functions of poultry gastrointestinal tract

Achieving maximum broiler genetic potential has been largely dependent upon optimal poultry GIT function, in which six vital parts have been identified as being involved: 1) feed intake regulation; 2) mechanical, enzymatic, and microbial digestion; 3) intestinal absorption, 4) metabolism regulation; 5) immune protection; and 6) bacterial colonization. The amount of feed consumption was a basic factor that determined the rate of growth and body composition achieved by poultry throughout their lifecycles. The physiological and physical regulation of feed intake requires the presence of sensors within the GIT. As an interface between the external environment and the body, the most important function of the GIT is to extract nutrients from feeds to support growth, maintenance, and reproduction. Meanwhile, the GIT is the largest endocrine gland, which produces at least 20 hormones, regulatory peptides, and their receptors (Ahlman and Nilsson, 2001), as well as being largest part of the immune system comprised of the lymphocytes and other immune cells of the gut associated lymphoid tissue (GALT) (Casteleyn et al., 2013). Furthermore, the GIT harbors an enormous microbial community that may have either positive or negative influences on birds.

With so many important functions, the GIT has been shown to consume an enormous amount of nutrients for its development, maintenance, renewal, and normal function. The GIT was reported to be a major consumer of metabolic energy, using about 20% of all ingested energy (Cant et al., 1996), and it had the highest daily rate of protein synthesis of all the body tissues and synthesized more than 20% of whole body proteins (Van Der Meulen and Jansman, 1997).

2.2 Anatomy and physiology of poultry gastrointestinal tract

A diagrammatic overview of the internal organs of the female chicken is shown in Figure 1-1, and the gross anatomy of the broiler GIT is shown in Figure 1-2. The broiler GIT system has been described as a continuous tube that opens at either end (beak and vent) to the outside world and consists of a beak-oral cavity, esophagus, crop, proventriculus, ventriculus or gizzard, duodenum, jejunum, ceca, rectum, and cloaca. As food progresses through these organs, a specific sequence of digestive events occurs, including grinding, acidifying, hydrolyzing, emulsifying, and transporting of the end products.

The beak, tongue, and oral cavity function in grasping, testing, mechanical processing, and lubricating food and propelling the food to the esophagus, with anatomic adaptations for shelling seeds and selecting coarse particle. The esophagus extends down the neck into a sizeable crop for storing food, so that large meals can be consumed, and terminates in the proventriculus. The general understanding of poultry stomach system consists of the proventriculus (glandular stomach) and the ventriculus or gizzard (muscular stomach). The proventriculus is the site where digestion is initiated, and where the tubular glands that secreted mucous and the gastric glands that secreted hydrochloric acid and pepsin are identified. The function of the gizzard is to mechanically grind food for particle size reduction and surface area increment. It also serves as a gastric mixer for acid and pepsin mixing with food during passage through the proventriculus. The duodenal loop of the intestine encircled the pancreas and received the pancreatic and hepatic ducts. The jejunum and ileum have not been clearly demarcated in birds. The ceca aids in digestion and water balance. The colon is connected the ileal junction and the cloaca. The cloaca is the terminal chamber that serves as a storage area for urine and feces. The vent is a transverse slit that has lips on both the dorsal and ventral sides.

The intestinal sections have been described as vital because much of the digestion and all of the absorption takes place in these tissues. The intestinal wall is composed of the same four layers as the rest of the intestines; mucosa, sub-mucosa, muscular tunic, and serosa (Ziswiler and Farner, 1972). The mucous membrane has a velvety appearance due to the presence of numerous, projecting villi, which are actively involved in absorption of nutrients

(Yamauchi, 2002). Two muscle layers, the inner circular and outer longitudinal, are responsible for mixing the digesta and propelling it through the intestines. The villi contained a rich capillary bed, which collected absorbed nutrients and transferred them to the portal blood vessels. The villi form a zig-zag arrangement that is believed to slow digesta flow and increase surface area (Denbow, 2000). Epithelial cells of the villi have about 10^5 microvilli per square millimeter on their apical surface, which increased the absorbing surface area 15-fold (Ziswiler, 1986). The lining epithelium contained chief cells, goblet cells, and endocrine cells. The epithelial cells that line the villi are derived from the crypts of Lieberkuhn. The crypts contained undifferentiated cells, goblet cells, endocrine cells, and lymphocytes. Paneth cells were present on the sides and troughs of the crypts (Denbow, 2000).

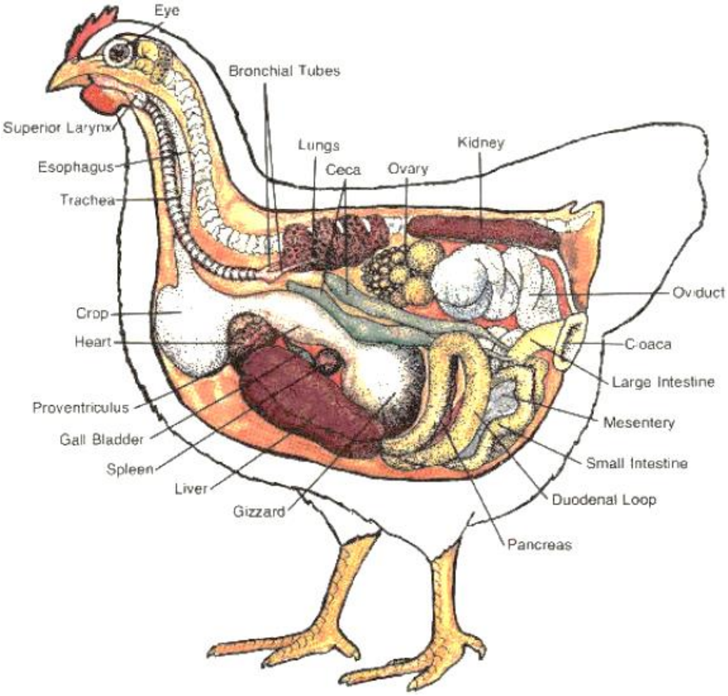

Figure 1-1. The internal organs of the female chicken (Jacob, J., and T. Pescatore)

The liver, gall bladder, and pancreas are important accessory organs of the digestive system. The pancreas lies within a loop of the duodenum. The digestive enzymes produced in the tubular acinar glands of the pancreas are shown to be collected into ducts. Avian pancreatic juice contained enzymes similar to those of mammals, including amylase, lipases, trypsin, and chymotrypsin. Another major function of the pancreas is to produce insulin so that all the body cells are supplied with glucose. The pancreas also produces bicarbonate, which buffers intestinal pH. The liver has two lobes of nearly equal size. Its primary digestive role is the production of bile acids and bile salts. Bile acids and salts, phospholipids, and cholesterol are secreted into the bile canaliculi and collected by the bile ducts. The bile is stored in the gallbladder or secreted directly into the duodenum as the bird has the unique presence of two bile ducts.

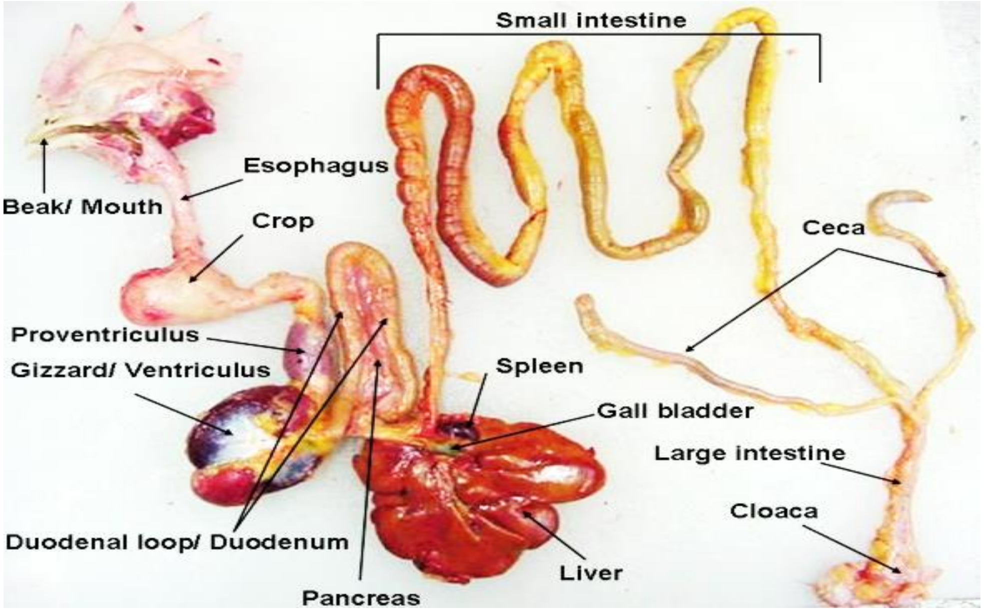

Figure 1-2. The gross anatomy of the broiler gastrointestinal tract (Jacob, J., and T. Pescatore)

2.3 Unique features of poultry gastrointestinal tract and function

Although the overall digestive enzymes and biochemical processes have been found to be similar in poultry and mammals like pigs, poultry have a different anatomy and physiology that has some specific differences in nutrient digestion and absorption. Generally speaking, the distinctive anatomy and physiology of the poultry GIT reflects the constraints of requiring less weight for flight and a preference for physical attributes of foods available in the natural habitat. However, genetic selection for industrial broiler production, accompanied by highly processed feed, has created sharp contradictions with natural GIT functions. Furthermore live performance improvement should consider nutritional and feeding strategies that take advantage of the unique anatomic and physiological features of the broiler GIT.

2.3.1 Feed consumption

Poultry have specific visual and tactile discrimination that has evolved to select, prehend, and swallow food in a voracious manner. Chagneau et al. (2006) reported that visual cues are mainly involved in poultry feed selection. The chicken possess normal vertebrate trichromatic vision (Cornsweet, 1970) and can readily be trained to discriminate colors (Bell and Freeman, 1971). Immediately after hatching, chicks are attracted by feed that exhibited light and bright colors (Rogers, 1995). Field trials showed that short wavelengths (green and blue) generally increased body growth and feed efficiency (North and Bell, 1993; Prayitno, 1994; Khosravinia, 2007). The beak and tongue are the major medium for tactile cues (Picard et al., 2002), as well as the presence of sensors within the GIT (Ferket, 2006). Tactile stimulation of the tongue by food causes a series of rapid posterior tongue movements that pushes the food into the pharynx. Feed hardness, size, shape, and consistency are important to poultry feed consumption (Melcion et al., 1995). Chagneau et al. (2006) reported the apparent efficiency of pecking (milligrams of feed taken per peck on average) varies mainly with the size of the feed particles. Day-old chicks learn to associate nutritional effects with the sensorial characteristics of feed particles (Hogan, 1984). Adjustment by the bird to physical factors, such as the hardness of pellets or the size of particles, has been suggested to be much faster than nutritional factors (Nir et al., 1990).

The chicken utilizes vision, taste, and tactile senses to select food, while social order, social stimulation, and availability of feed influenced feed consumption (Nielsen, 1999). However, it has been reported that the sense of smell is considered to be poorly developed in the chicken (Picard et al., 1999).

"Eating like a bird" has incorrectly suggested that birds had relatively small appetites, whereas in fact the typical wild bird consumes about a third more dry matter each day than does the typical mammal (Nagy, 2001). Furthermore, the significantly increased BW of commercial broiler is partly due to increased appetite through genetic selection (Appleby et al., 1994). Birds have been reported to have high basal metabolic rates than mammals, which correlates with their higher body temperature and flying requirement, and thus they use energy at higher rates. Maintaining maximum feed intake has become the single most important factor in commercial broiler production environment that will determine the rate of growth and efficiency of nutrient utilization.

2.3.2 Stomach System

The typical animal stomach performs five basic functions, which included feed intake regulation, acid and enzyme secretion, mechanical particle size reduction of ingested feed, enzymatic disruption of chemical bonds, as well as mixing and transporting. The stomachs of swine and poultry are shown in Figure 3. The swine stomach is a single muscular organ with four distinct areas (oesophageal, cardiac, fundic and pyloric regions) that are found to be responsible for storage, secreting hydrochloric acid, initiating the breakdown of nutrients, and passing the digesta into the small intestine. In contrast, poultry have developed a separately functioning stomach system with crop, proventriculus, and gizzard, each of which exhibited distinctly independent functions, such as food storage and intake regulation, and mechanical and enzymatic digestion processes. The crop is generally not included as a part of the poultry stomach, although its feed intake regulation function has been known for a long time. The morphology of the poultry crop, proventriculus, and gizzard is unique among vertebrates, and has evolved to accommodate a wide range of dietary opportunities (Langlois, 2003). This stomach system plays a crucial role in providing an adequate environment for feed intake regulation, as well as physical and chemical reduction of the size and molecular complexity of a diet.

The crop has not only functions as a temporary storage site (Hill, 1971), but it also exhibits feed intake regulation attributes, and works to soften feed (Hainsworth, 1972; Buyse et al., 1993). It can send hunger or satiety signals to the brain, and distension due to feed consumption increases the activity of the vagus nerve that signals the satiety center of the hypothalamus in the brain. This suggests that the physical characteristics of feed or feed form may influence the amount and time of feed consumption. Considerable microbial growth and fermentation occurs in the crop, which may be beneficial to the bird.

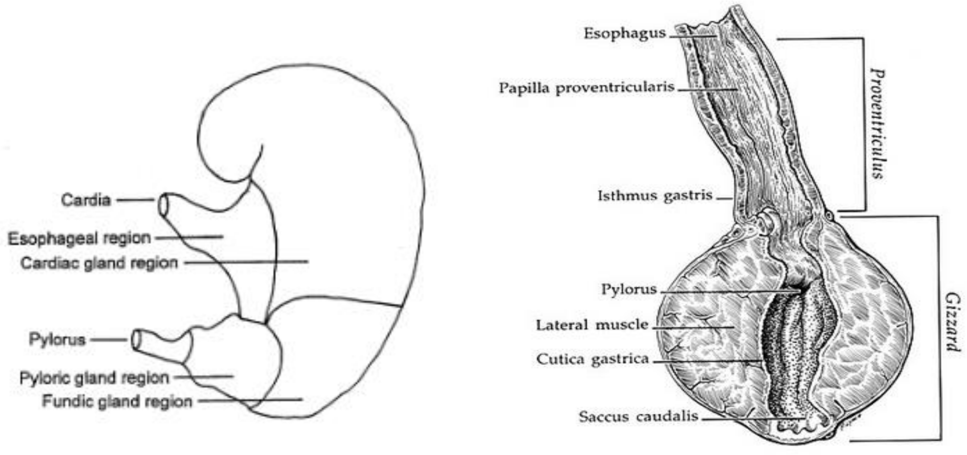

Figure 1-3. The stomach structure comparison of swine and poultry

As the glandular stomach, the major function of the proventriculus is gastric digestion, which is expedited by enzyme (pepsinogen) and hydrochloric acid secretion. The proventriculus is described as a fusiform organ, which varies in size and shape among avian species. The proventriculus is relatively small in granivorous species and relatively large in carnivorous and piscivorous species (King, 1984), which emphasized the importance of the proventriculus in protein digestion. Mucous secreting cells also lined the main duct of the gastric gland, and the alveoli of the glands were lined by oxynticopeptic cells, which secret both hydrochloric acid and pepsinogen (McLelland, 1990).

The muscular stomach, the gizzard, which had no equivalent in the mammalian GIT, functions as a gastric grinder (instead of teeth) for mechanical feed particle size reduction into a form that is more accessible for enzymatic degradation in the small intestines. The gizzard consists of two pairs of smooth muscles arranged in distinct bands that both originate and terminate on a circular tendon. The asymmetrical arrangement of these four muscles provides mixing and grinding actions during contraction. High myoglobin concentrations give these muscles their distinctive red coloration. The interior lining of the gizzard contains numerous deep tubular glands that produced a protein-rich secretion that hardened into rod-like projections (Akester, 1986). These rods are described as trapping desquamated epithelial cells to form the cuticle lining of the lumen. The cuticle acts as a grinding surface and protects the underlying mucosa from digestion by acid and pepsin secreted by the proventriculus. The rods (~20 nm in diameter) also increased the abrasiveness of the cuticle.

The major function of the gizzard is to decrease the size of food particles, increase their surface area, and promote gastric proteolysis. In addition, another important function of the gizzard is found to be as the pacemaker of gut motility (Ferket, 2000), which regulates feed intake (Chaplin et al., 1992), influences digesta flow, and stimulates bile and enzyme secretion (Li and Owyang, 1993; Svihus, 2004; Hetland et al., 2003). Large, non-soluble particles (such as small stones or grit), can be retained in the gizzard until feed and digesta are ground into a certain particle size by the action of the muscles and exposed to acid from proventriculus, which increases ingesta retention time and improves nutrient digestibility.

Gizzard development is improved substantially when dietary structural materials were fed (Hetland et al., 2003; Amerah et al., 2008). Due to the reported improvement in nutrient availability when structural components that stimulates gizzard development are added to the diet, several authors suggested to include an appropriate amount of structural material in the diet, and allow birds to ingest stones and grit so they can retain them in the gizzard as gastroliths to enhance the efficiency of mechanical food breakdown (Stevens and Hume, 1995; Moore, 1998b; Gionfriddo, 1999; Mackie, 2002; Wings, 2007).

2.3.3 Intestine, peristalsis, and reverse peristalsis

The advantage afforded by flight has also brought an evolutionary pressure to keep the size and weight of the digestive tract to a minimum. During the process of evolution, those avian species that developed simple but effective digestive systems were apparently more able to both digest nutrients and fly. The GIT of the broiler is relatively shorter than that of pig, being only 120 cm (Chapter V) long as compared to 15 to 22 m in pigs (Getty, 1975; Mochizuki and Makita, 1998). The GIT is also centralized within the body cavity to optimize aerial maneuverability. The intuitive effect of a shorter GIT length was less total surface area and reduced digesta retention time. The surface area of the small intestines, where breakdown of substrates and absorption of their monomers occurs, tends to be less than that of mammals, as is the small intestine length (Caviedes-Vidal et al., 2007; Lavin, 2007). Small intestine volume, a direct function of tube length and area, and consequently the potential mass of digesta carried, is thus relatively smaller in birds. Birds are seemingly at a disadvantage relative to mammals as Lavin (2007) found birds have significantly shorter mean retention times of both fluids and particles within the gut lumen than mammals (on average about 75% shorter).

Birds appear to be faced with having to satisfy relatively high energy needs with relatively low absorptive surface area within a relatively short time period (Caviedes-Vidal et al., 2007). Nevertheless, birds exhibits similar digestive efficiency as compared to other animal species. With regards to enzymatic digestion efficiency, Bairlein (1999) found no significant difference in mean energy utilization efficiency between reptiles and birds in hundreds of feeding trial determinations. In a similar manner, Robbins (1993) found little difference between birds and mammals. With respect to mechanical digestion, Fritz et al. (2011) reported that there was no significant difference in mean fecal particle sizes between birds and mammals, which indicates a comparable efficiency of food processing by gizzards or teeth. These findings may appears illogical and introduces a question as to whether or not birds have any unique mechanism in their digestive system that compensated for reduced GIT length and retention time relative to mammals.

However, peristalsis and reverse peristalsis are part of an important strategy to compensate for morphological disadvantages. Peristalsis moves the digesta from the esophagus towards the vent. Food enters the crop when the gizzard contracts and exits the crop when the gizzard was relaxed. Food is pushed out of the crop by contractions of the crop wall. The rate at which food is pushed out of the crop is not influenced by particle size or their solubility, but rather by peristaltic waves generated by the gizzard. During primary peristalsis, there is a cessation of spontaneous electrical activity that is associated with relaxation of the muscular wall. This cessation is followed by a propagated, long-lasting spike burst of high amplitude. As the peristaltic wave moves abroad, it is preceded by inhibition of the muscles in front of the wave (Vergara et al., 1989). Primary peristalsis is mediated entirely by the extrinsic nervous system (Mule, 1991).

Reverse peristalsis is a unique motility phenomenon of the poultry digestive tract. Research into the avian digestive anatomy has been extensive over the years, but investigations into the motility of the digestive tract have been largely neglected. Reflux, or reverse peristalsis, might be the very important mechanism that birds have developed to offset the disadvantage of shorter retention time in the short GIT (Moran, 1982). Digesta moves in the general direction of mouth to vent with peristalsis, but in many species of birds that have been studied, this posterior flow is interrupted by opposing refluxes. Retrograde movement of digesta occurs within 4 intestinal segments: 1) the proventriculus and the gizzard; 2) the small intestine and the gizzard; 3) the rectum and the small intestine; and 4) the cloaca and the rectum (Duke, 1994). The reflux of digesta between the proventriculus and gizzard is thought to be necessary to optimize the action of enzymatic and mechanical digestion, whereas the reflux from cloaca to rectum is necessary because of the need to absorb protein, salts, and water present in the urine (Duke, 1989; Klasing, 1998). Studies in a variety of species have demonstrated a complex cycle of proventricular, gizzard, and duodenal contractions that propelled food in alternate directions between these three organs (Hill, 1971; Clemens, 1975; Sklan, 1978). Sacranie et al. (2012) reported that broilers exhibited reverse peristaltic contractions of sufficient magnitude to propel chromium EDTA from the cloaca to the gizzard, and Yi et al. (2013) found that the marker appeared in duodenum after being injected via the cloaca. Chickens utilize intestinal reverse peristalsis in combination with forward peristalsis to mix gastric acid, bile, and pancreatic enzymes with the feed components, and slow the feed flow, which allows for better absorption of the nutrients by the intestinal villi and help stabilize the intestinal flora.

2.3.4 Gastrointestinal tract flexibility

One hallmark of poultry is their morphologic and metabolic flexibility. The size of the GIT, especially the gizzard, quickly responds to feed structure. It has been reported in wild turkeys that the gizzard and cecal sizes are smallest in the summer when the birds feed on tender shoots of newly growing herbaceous plant, while the gizzard was largest and ceca was longest in the winter when birds fed primarily on woody stems, buds, and leaves (Korschgen, 1967). The time required for adaptive hypertrophy appears to be about 2 to 3 months. The extreme of the metabolic flexibility of chickens is demonstrated by their ability to thrive on a 100% meat diet (Myers et al., 1999), while modern production practices illustrate that they could also live as a granivore, eating virtually only the seeds of corn and soybeans.

The avian GIT has a larger number of enteric organs with greater coordination with each other than their mammalian counterparts (Klasing, 2005), which makes the entire system very efficient. There are specific sites for functions, such as storage, enzymatic digestion, and mechanical digestion divided among the crop, proventriculus, and gizzard, respectively. The crop, proventriculus, and gizzard could be considered to be an integrated stomach. The interaction between gizzard and proventriculus has been observed in studies. The present author found a larger gizzard often coincided with a smaller proventriculus in the presence of CC, and vice versa (Yi, 2011), which suggests that poultry GIT adjusts digestive functions according to feed composition and structure. Feed is initially ground in the gizzard, followed by reflux of larger food particles back into the proventriculus for addition of fresh pepsin and acid. With the aid of reverse peristalsis, large particles are held within this proventriculus and gizzard cycle for some time, which reduces the requirement for acid and pepsin. Evidently, proventriculus dilatation is often observed in the presence of fine mash diets, which indicates that the proventriculus needs to secret more acid and pepsin to support a higher rate of passage in order to achieve optimum digestion.

Modulated proventriculus function, due to feed structure, changes the pH environment in GIT, which consequently influences the intestinal function. It has been shown repeatedly that when structural components, such as whole or coarsely ground cereals, or fibrous materials like rice hulls or wood shavings are added, the pH of the gizzard contents decreases by a magnitude of between 0.2 and 1.2 units (Gabriel et al., 2003; Engberg et al., 2004; Bjerrum et al., 2005; Senkoylu et al., 2009). Reduced pH is more conducive to amylase activity (Pinchasov and Noy, 1994) and pepsin activity (Gabriel et al., 2003), reduced risk of coccidiosis (Cumming, 1994), and provides an acidic inhibitor to pathogens proliferation (Engberg et al., 2002; Mikkelsen et al., 2004). The logical explanation for this response is an increased gizzard activity and a longer retention time that allows for an accumulation of acid.

2.3.5 Hind gut nutrition

Poultry have developed various mechanisms to process undigested residue that escaped the small intestine. For mammals, microbial fermentation in the hindgut synthesizes essential nutrients (vitamins and essential amino acid) and microbial fermentation converts indigestible cell wall material into available energy in the form of short chain fatty acids. However, the colon or rectum is short in most avian species, and does not have significant capacity for microbial fermentation (Klasing, 1998). The ceca of birds has many functions, including absorption of water and other nutrients, conservation or detoxification of nitrogen, and fermentation. In chickens, the cecum achieves any of these purposes, depending upon the diet.

3. THE INTERACTION BETWEEN FEED STRUCTURE AND BROILER GASTROINTESTINAL TRACT FUNCTION

Great effort had been made on the study of chemical composition of feeds by nutritionists. However, the physical characteristics of the feed have also become very important subject of study in birds (Savory, 1979; Hamilton and Proudfoot, 1995; Picard et al., 1999), as these may exert an influence on GIT development, motility, and function. Altered GIT motility and maintenance requirements with certain anti-nutritional factors, such as Non-starch polysaccharides (NSP) content in wheat, have provided clear evidence of the interaction between feed and GIT function. The intestine responds to NSP content in terms of length, weight, absorptive area, and rate of turnover of enterocytes (Goodlad, 1990, Savory, 1991, Brenes, 1993), while the intestinal bacteria population is also modulated, which in turn influences gut morphology, nutritional metabolism, pathogenesis of intestinal disease, and immune response of the animal. Coarse particle preference, the unique stomach system, reverse peristalsis, and the intro-organ cooperation all provide the theoretical bases required to optimize poultry GIT function with simple modifications of feed structure. The successful application of whole wheat in the EU has provided a good example upon which to build this hypothesis.

The interaction between feed structure and GIT function has challenged one fundamental assumption of feed formulation, which assumes the additivity of nutrition, independent of physiological status of the animal. Generally, many nutritionists have not fully considered such an interaction between feed and GIT, and has only assumed the ingredient's nutritional values required to meet animal energy and amino acid requirements. However, feed structure may change development, motility, and maintenance of the GIT, which influences the intestinal efficiency of digestion and absorption, and could influence overall body maintenance requirements that accounts for a large part of the total daily energy requirement that should be accounted for in the dietary formulation.

Following the above discussion, in order that GIT function be optimized through the unique interaction with feed structure, there are two main factors that should be considered: digesta retention time and particle size. Although poultry have a relatively shorter digesta retention time due to a relatively short GIT, birds compensate by several means including food storage in the crop, gizzard grinding and screening, and GIT reverse peristalsis. A paradoxical role of feed particle size in poultry nutrition has been recently recognized, where fine particles benefited nutrient absorption through a surface area effect, whereas coarse particles affect GIT development and function from a physiological perspective. Moreover, as has recently been demonstrated, retention time in the gut and the efficiency of particle size reduction (i.e., gizzard grinding ability) has a complementary relationship (Chapter 3). Large herbivorous mammals, species with relatively low chewing efficiency, have a relatively long digesta retention times (Clauss et al., 2009). Furthermore, cooperation between organs, such as the proventriculus and gizzard may also contribute to the enhanced overall digestibility. The instinctive preference of poultry for larger particles, and the successful whole wheat application in the EU are logical reasons to explore the interaction between feed structure and GIT development, integrity, maintenance, motility, and function in the present study. A better understanding of the interaction of feed structure with GIT development and function has become critical to optimize feed manufacturing strategies and broiler live performance, as well as minimize environmental impact.

3.1 Whole wheat and coarse grain inclusion

During the 1990s, the inclusion of whole wheat in broiler chicken diets became more common in EU countries. This feeding regimen consisted of adding a small amount of whole wheat beginning at one week of age, and gradually increasing the inclusion level of whole cereals up to 25% at slaughter age (Hetland et al., 2002). The use of locally-grown whole cereals reduced feed costs due to reduced transportation and processing cost.

With the consumption of whole grain, a higher relative gizzard weight was observed, which was apparently due to an increased frequency of gizzard contraction (Hill, 1971;

Roche, 1981) to provide the additional grinding needed to process large particle ingredients for further digestion in the distal parts of the intestines.

A visually enlarged proventriculus has previously been reported as one of the effects of whole grain inclusion (Forbes and Covasa, 1995). As the thickness of the proventriculus wall is mainly due to glands located in the mucosa, dilation may be a consequence of the dilation of these submucosal glands (O'Dell et al., 1959). Moreover, some degeneration of the glands has been reported, as well as an increased cell number, mucous secretion, and distended musculature (O'Dell et al., 1959). The dilation of sub-mucosal glands may have led to reduced stimulation of gastric juice secretion and may explain the higher pepsin activity observed in the proventriculus tissue of whole wheat fed birds.

The liver and pancreas weight are expected to increase with structural material inclusion in the diet. Rougiere (2009) reported pancreas weight increased with coarse diets (30% coarsely crushed corn), and relative pancreas weight increased with 200 to 400 g/kg whole wheat feeding (Banfield et al., 2002; Engberg et al., 2004; Wu et al., 2004), but no difference was observed with 100 to 200 g/kg (Ravindran et al., 2006). Higher bile salt concentration in the jejunal content may have been due to greater gizzard activity as was observed in the presence of oat hulls (Hetland et al., 2003; Svihus et al., 2004).

Whole wheat-fed chickens have both a lower pH in the gizzard contents and a greater pepsin activity, which probably increases the denaturation and hydrolysis of dietary proteins (Gabriel et al., 2003; Engberg et al., 2004). A higher degree of grinding of feed and more protein hydrolysis would be expected to increase the efficiency of digestion. Conversely, with a fine particle diet, the feed is less exposed to low pH and proteases in the gizzard due to more rapid passage, and ingested feed appears more quickly in the duodenum as a suspension of relatively unchanged particles (Hill, 1971). These poorly digested feed particles in the upper small intestine may have played a role in the development of aberrant bacterial populations such as *Clostridium perfringens*, the pathogenic agent of necrotic enteritis, or *E. coli*, as suggested by Cumming (1994). Moreover, a higher pH may limit bactericidal action in the gizzard.

However, whole wheat feeding has been observed decrease some brush border intestinal enzyme activities, such as leucine aminopeptidase in the duodenum and maltase in the ileum. Although it seems to have no negative effect on growth and feed efficiency in healthy birds, in the case of deterioration of the intestinal mucosa caused by intestinal disease like enteritis or coccidiosis (Yashpal, 2013) that partly destroy the intestinal mucosa, this may have limited the final stage of digestion, which could be detrimental. More studies were required to determine the full consequences of incorporation of whole wheat on digestive physiology and interaction with enteric diseases.

3.2 Feed Form and Pelleting

As discussed above, the physical form of the feed has been known to influence broiler gut function as a natural adaptive response of the animal. Generally, feed is presented to poultry in several forms, mash, pellet, or crumble. Meat birds fed pellets exhibit advantages in growth and feed efficiency over birds fed mash. This is a generally acknowledged fact was that improved performance from pellet feeding could be attributed to increased feed intake and eating speed, decreased feed wastage, reduced selective feeding, destruction of pathogenic organism during pelleting, and improved palatability (Bennett et al., 2002; Brickett et al., 2007). However, other beneficial effects of pelleted feed have also been reported.

Improved digestibility of nutrients may arise from an influence on intestinal morphology. Nir et al. (1995) observed that pelleting resulted in a decrease in the weight and contents of the proventriculus, gizzard, and small intestines, as well as a decrease in small intestine length (Nir et al., 1994). This agreed with the subsequent findings of Amerah (2007), who observed that the improvement in bird performance with pelleting was accompanied by a decrease in the relative length of all components of the digestive tract. Mirghelenj (2009) reported the weight of gizzard and caeca increased in pellet or pelleted-crumble fed birds as compared to mash fed birds, whereas other gastrointestinal segment weights and carcass yield were not affected by physical form of the diet. Generally, relative gizzard weight is reduced with increasing weight of the bird consuming a pelleted diet (Hetland et al., 2002).

Pelleted diets have also been reported to influence the intestinal micro structure. Villi and crypts are the functional units of the small intestines and have assumed the role of digestion and absorption. Morphological alterations of the intestine have affected function, secretion of digestive enzymes, and absorption of nutrients. Dahlke (2003) reported that pelleted diets promoted a greater number of villi in the duodenum, as well as greater crypt depth, but without alteration in villus height when compared to a mash diet. Zang (2009) reported that pelleted feed might have enhanced performance through improved nutrient metabolism and digestive tract development. An increased villus height:crypt depth ratio within the duodenum, jejunum, and ileum was observed in birds fed a pelleted diet when compared with those provided a mash diet. Amerah et al. (2007) also found that a pelleted broiler starter feed increased villus height:crypt depth as compared to mash diets.

Interestingly, altering feed structure has been shown to influence Salmonella infection in several studies with pigs. It is also known that physical properties of feed influences pH, microbial populations, and volatile fatty acids (VFA) in the digestive tract of broilers (Engberg et al., 2002). Huang (2006) reported that pelleting feed increased the incidence of Salmonella in the contents of gizzards and ceca of growing broilers.

Two main physical indicators of pellet quality have been described: hardness and pellet integrity. The former is measured by pellet resistance to breaking when submitted to external pressure, and the latter is measured by the percentage "fines" produced during transportation from the feed factory to the farm, and subsequent distribution in the feeding system at the farm. Parsons (2006) reported that broilers fed hard pellets had significantly greater BW gain and feed efficiency than those fed soft pellets. Performance benefits of hard pellets in comparison to soft pellets may be derived by similar mechanisms, as observed with increased corn particle size of mash diets. Nitrogen and lysine retention were significantly improved with broilers fed hard pellets as compared to those fed soft pellets. In addition, hard pellets had significantly higher TMEn than soft pellets. However, carcass characteristics were not affected by pellet hardness. These findings imply that a harder pellet texture produces beneficial digestive and subsequent performance effects than pellets of softer texture in a manner similar to coarse feed particle.

Broiler performance benefits associated with pelleting have been well documented. However, benefits were only realized if pellet integrity was maintained up to the point of consumption. Hu et al. (2012) reported that birds fed 100% pellets had greater feed intake and BW than birds fed 50% pellets. Zatari et al. (1990) showed that pellets of poor quality, simulated by a 25:75 pellet to fines ratio, diminished predicted live performance improvements associated with pelleting. Moritz et al. (2003) determined that incorporating water into feed formulations increased pellet durability, decreased fines, and improved broiler performance when compared with feeding pellets of lower moisture. Mckinney et al. (2004) estimated that the process of pelleting contributed an extra 187 kcal/kg of diet at 100% pellet, which declined in a curvilinear manner as the percentage of whole pellet decreased. It was also observed that as the proportion of pellets in the feeder increased, birds consumed less frequently and rested more frequently. Thus, less energy was expended by feeding behavior.

3.3 Grain particle size

The particle size reduction is the central paradigm of feed milling, and the grinding of whole grain for broiler feeds has constituted the second greatest energy expenditure after pelleting (Reece et al., 1985). The purpose of grinding feed ingredients is to increase particle homogeneity, improve the batching and mixing efficiency, decrease ingredient segregation during the further handling, enhance pelleting quality and efficiency, and improve nutrient digestibility by increasing substrate surface area. The challenges of increased feed milling energy cost and more expensive feed ingredients have created a demand for new strategies to control feed costs while optimizing the efficiency of broiler performance.

The successful application of whole wheat in the EU poultry industry has been used as a good example to support the concept that other coarse grains could be successfully included into poultry diets for improved gut health, growth efficiency, and considerable energy and time savings during feed manufacturing (Cumming, 1994; Preston et al., 2000; Plavnik, 2002), due to its interaction with the GIT of poultry (Svihus, 2001; Bennett et al., 2002; Rodgers et al., 2012).

Research on optimal grain particle size in poultry feed, specifically for corn particle size, had yielded inconsistent results and assumed a paradoxical role in poultry nutrition. Lott (1989) reported 21 d broiler performance to be depressed when corn particle size increased from 716 to 1196 μm, but Nir et al. (1994) reported that 21 d broiler performance was improved as corn particle size increased from 525 to 897 μm. Jacobs (2010) showed that there was no consistent effect on either BW gain or feed efficiency across 3 experiments with corn particle sizes of 557, 858, 1,210, and 1,387 μm. The complexity of the diet, grain type (Kilburn et al., 2004), feed form (Mirghelenj, 2009), bird age (Lott et al., 1989), litter availability, feed mill type, environmental temperature (Lott et al., 1989) and further processing of feed (pelleting or crumbling) (Goodlad et al., 2002) appear to confound the influence of diet particle size on growth performance. Nevertheless, management of the interaction between grain particle size and gizzard function was certain to change GIT function, which might be the direct reason for improved digestibility and performance that has been often observed.

Particle size has a paradoxical role in poultry digestion, especially concerning the interaction between gizzard activity and GIT motility and function. It was previously thought that finely ground grain would enhance nutrient utilization and growth efficiency due to increased surface area and improved pellet quality (Goodlad, 2002). However, larger particles have enhanced gizzard activity and increased gut retention time for nutrients, and promoted better digestibility through prolonged enzymatic processing. Thus, from this point of view, the particle size distribution seems to be more important than average particle size. The best particle size distribution appears to include a minimal proportion of coarse particles that stimulates gizzard function and a majority proportion of fine particles with greater surface area for better nutritional digestion and absorption. Meanwhile, the typically used hammermill grinding only creates a wilder particle size, which means larger sgw for hammermill grinding particle as compared to roller mill grinding, as shown Figures 1-4 (Anderson, 1994), which does not fully satisfy the different particle size requirements of the gizzard and intestine. The concept of and the geometric mean diameter by mass (dgw) does not make sense upon this point. Thus, presenting a biphasic distribution of particle size (some coarse and some fine) is very interesting and may have great practical utility.

The fact that GIT function changes in concert with gizzard weight may alter nutrient digestion and absorption and potentially influenced broiler performance. A coarse diet enhances the development of the foregut, which increases feed intake, maintains pH barriers

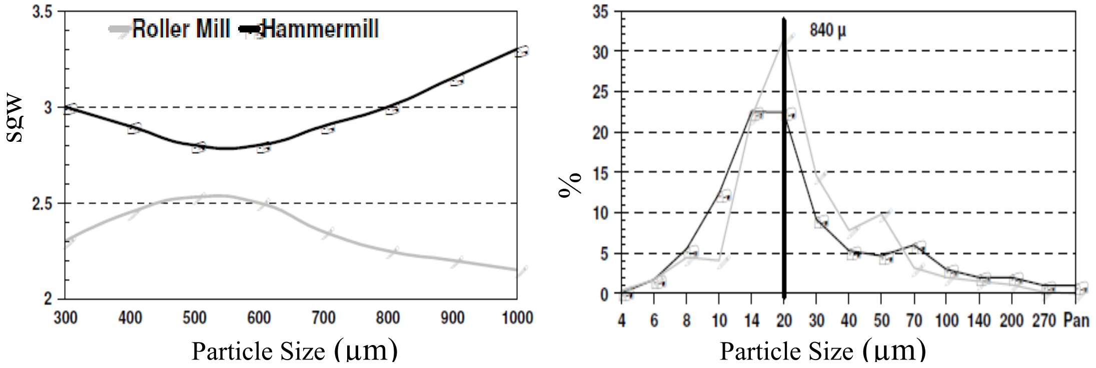

Figure 1-4. Particle size standard deviation (left) and particle size (840 microns) distribution (right) by roller mill and hammermill with US #2 yellow corn (Anderson, 1994).

throughout the gut (Engberg et al., 2003), increases GIT motility, and extends digesta retention time. This is beneficial for both health and performance throughout the growing period of commercial broilers. Broilers fed diets containing CC have been observed to significantly increase feed intake and improve feed efficiency as compare to birds fed mash diets. The development of the digestive tract of poultry, especially the gizzard, is known to be influenced by feed particle size, which is evident by 7 d of age. Nir et al. (1994) reported greater gizzard development and low gizzard pH in 7-d-old chicks fed medium or coarse particle size diets as compare to those fed fine particle diets. So, these researchers reported a positive relationship between gizzard weight and dietary particle size. Similarly, Healy (1992) reported increased gizzard, proventriculus, and intestinal weights for chicks fed corn ground to 900 µm as compared to those fed corn that ground to 300 µm. In contrast, it has been shown that finely ground diets may have inhibited the contraction of the GIT, including the refluxing activity of the gut in commercially raised broiler chickens. Dissections of birds that have consumed finely ground diets showed less developed gizzards as compared to animals that had been fed coarsely ground diets. This observation demonstrates that the gizzard not only functions as a transit organ but rather as a grinding organ (Cumming, 1994). It can be hypothesized that for chickens consuming diets with large particles, which the gastric region and cause an increase in GIT mobility, an increased feed intake will be observed. Consequently, their performance and GIT health will be improved (Engberg et al., 2002).

The response of intestinal absorptive capability to structural material has been observed with conflicting results concerning villi number and height, and crypt depth. Reduced relative duodenal weights were found in birds fed coarse particle diets (Nir et al., 1995), and a similar pattern was also reported in birds fed diets containing whole wheat (Gabriel et al., 2003). Dahlke (2003) reported that corn particle size did not influence the number of duodenum villi, but as particle size increased, there was a linear increase in villus height and crypt depth in the duodenum. Amerah (2008) reported that the villus height, crypt depth, and epithelial thickness in the duodenum were unaffected by particle size and grain type in pelleted feed. Dahlke (2003) thought that broilers fed ingredients with larger particle size exhibited a slower rate of passage through the GIT, which results in greater contact between the food and the intestinal mucosa accompanied by an increase in villus height. Further histological analyses will be required to fully explore the morphological response of the intestine to structural material.

A significant increase in amylase activity and bile acid concentration has been observed when birds are fed diets that contain more structural components (Svihus et al., 2004). This response may indicate increased secretory activity caused improvements in nutritive value, which is sometimes observed by dietary inclusion of whole wheat or other structural components (Plavnik et al., 2002; Hetland et al., 2003; Svihus et al., 2004). This hypothesis was also supported by the fact that amylase activity in the jejunum and starch digestibility in the anterior, median, and posterior ileum of individual birds exhibited a correlation of 0.56, 0.54, and 0.47, respectively (Svihus et al., 2004). The cause of this increased secretory activity has remained unclear, but it may be associated with a stimulation of pancreatic secretion caused by an increase in gizzard activity. Hetland et al. (2003) found a significant increase in amylase activity and bile acid secretion when gizzard activity was stimulated by dietary inclusion of oat hulls. The same tendency, although not significant for amylase activity, was observed when gizzard activity was stimulated by whole wheat in the feed.

The diet plays a very important role in determining the composition of the indigenous gut microflora and its effect on the host animal. Stimulation of gizzard development, through increased grinding activity, improves gut motility (Ferket, 2000), and increases the secretion of hydrochloric acid from the proventriculus into the gizzard and intestine, which ultimately decreases pH. A more acidic GIT environment may have an antimicrobial effect (Naughton and Jensen, 2001; Engberg et al., 2002). Enhanced digestibility in the foregut, due to dietary structural material, probably leaves fewer nutrients to support gut bacterial population in the hindgut. Overall, including larger particle size of grain in broiler chicken diets provides a method to potentially improve GIT health, particularly when antibiotic growth promoters were not included in the diet.

Past literature has also suggested that younger broilers may not be able to efficiently utilize large corn particles due to an underdeveloped GIT. Our present experiments demonstrate dietary inclusion of CC in pellet feed probably should be lower than 50% in the starter period and gradually increased with broiler age, as the broiler demonstrated a gradual adaptation to the larger particle size corn.

3.4 Insoluble Fiber

The dietary fiber fraction represents a diverse group of polymers present as cell wall and storage components in most feedstuffs. When ingested, dietary fiber components have interacted with the digestive processes along the entire GIT, and with the microbial community as well as with the structure and function of the gut.

Insoluble fiber has a paradoxical role in digestion and absorption. First, it obviously has an anti-nutritional effect by diluting nutrients and impeding absorption. However, recent findings indicate that insoluble fiber may also affect improved GIT health, enhanced nutrient digestion, and modulated animals behavior (Hetland et al., 2003). These roles include stimulation of gizzard development and digesta reverse peristalsis, which improves nutrient digestion and absorption. Many feed ingredients, such as barley, oats, and soybean meal contain a considerable amount of insoluble fiber (Knudsen, 1997). The dietary inclusion of 10% oat hulls in broiler diets was observed to increase wheat starch digestibility and stimulate gizzard activity (Hetland and Svihus, 2001). In addition, Hetland et al. (2003)

observed a higher total amount of bile acids in the gizzards of birds given access to wood shavings, indicating a gastro-duodenal reflux proportional to the amount of material in the gizzard, and supported their hypothesis that digesta reflux between the gizzard and duodenum was increased by access to insoluble fiber. This appeared to be a logical reaction by the bird to the presence of structural components, in that there was the obvious requirement to prolong the exposure of food to both the mechanical and chemical components of digestion in such a case. The large particle size of coarse hulls and their hardness, as a result of their insoluble fiber content, explain why birds consuming a coarse hull diet developed the heaviest gizzards. The coarse hull particles are retained in the gizzard until they are ground to a certain critical size that allowed them to pass through the pyloric sphincter (Clemens et al., 1975; Moore, 1998; Hetland et al., 2002, 2003). This leads to an increase in the volume of the gizzard contents and a muscular adaptation to meet the greater demand for grinding.

Bedding type can significantly affect growth performance and carcass quality of broilers (Billgilli et al., 1999; Malone et al., 1983). Litter type and condition affect litter consumption and intestinal bacteria (Malone et al., 1983; Lien et al., 1992), and thus may affect body weight and immunity of broiler chicks. Factors that can influence the efficiency of a type of litter include particle size, moisture content and buildup, rate of caking, and other physical characteristics of the material used. Bedding substrate may change particular behaviors of broiler chickens, such as nesting and dust bathing behavior, while the litter fiber may influence the gizzard function in a similar manner as dietary structural material. Wood shavings are the most commonly used litter materials, and re-utilization of old litter for several flock cycles is a common practice in commercial US broiler production. A major environmental emission issue with re-utilizing previously-used litter is the generation of ammonia. Ammonia is produced by microbial breakdown of fecal material in the litter, and it is well documented in the literature that ammonia production is favored by high moisture, litter nitrogen, temperature, and litter pH. High ammonia levels in poultry houses can result in poor bird performance and health, and a loss of profits to the grower and integrator. The typical practice to control broiler house ammonia concentration is to apply acidifiers, which has a limited time of effectiveness, and ventilation, which is expensive.

3.5 Anti-nutritional factors

It was well known that a variety of ingredients have profound and specific direct effects on the digestive system (e.g. raw soybeans, rapeseed) due to the presence of various anti-nutritional factors (trypsin inhibitors, lectins, tannins, NSP, etc.). As an example, intestinal viscosity increases with greater NSP level in the feed ingredients, and the rate of digestion is expected to decrease, a situation which should result in a lower nutrient density diet available to birds. The response to this condition includes increased intestinal mass and pancreatic size. Presumably, observable changes in GIT size have required greater extremes in viscosity to become apparent. Certainly, changes in pancreatic size seems to be more dramatic and sensitive in both wheat and barley-fed birds, indicating that enzyme output was modulated prior to changes in size of the digestive tract. Similarly, reductions in crypt depth and villi height have been observed in barley-fed chicks (compared with corn). Reduction of intestinal viscosity through use of the relevant exogenous enzymes has been shown to reduce relative weights and length of the crop, gizzard, proventriculus, duodenum, jejunum, and ileum in barley and wheat-fed birds.

Non-starch polysaccharidases (NSP) enzymes, which include cellulases and xylanases, have been routinely used in poultry diets that contain wheat, barley, oats, triticale, and rye and, more recently, maize. The beneficial responses observed may be based on one or more of three proposed mechanisms of action, namely: 1) cereal endosperm cell wall hydrolysis; 2) reduction in intestinal viscosity; and 3) provision of fermentable oligomeric substrates as a result of cell wall hydrolysis.

4. CURRENT STUDY

Great effort had been made on the chemical composition of feeds by nutritionists. However, the physical characteristics of the feed have also became essential to developing an effective and economical nutritional and feeding strategy for modern broilers upon the specific interaction between feed structure and GIT function. First, this review examined the unique morphological features that may facilitate the specific interaction between feed structure and GIT development and function, and it emphasized that the gizzard is the key pace setter of gut motility. Second, the research results on the interaction between feed processing and GIT development and function were reviewed. There were highly inconsistent results on the influence of coarse corn on broiler live performance, and the corn particle size and distribution, pellet quality, feed form, broiler genders, and litter condition could be the important confounding factors. Meanwhile, the influence of coarse feed structure on GIT motility, development, and function need further investigation. There was no question that coarse feed structure could stimulate the gizzard activity, but further investigation needs to be done on how enhanced gizzard function changes GIT motility, influences gut development, and alters GIT function.

The objective of the first experiment, Chapter 2, was to determine the response of broiler on different dietary CC inclusion levels in different feed forms on early GIT development of male chicks through 14 d of age. This chapter also studied the influence of dietary CC inclusion on selective feeding behavior and feces nitrogen content.

As litter condition and gender may confound the effects of dietary CC inclusion on broiler live performance, experiments 2 and 3 presented in Chapter 3 investigated the effects of gender, litter conditions, and dietary CC inclusion on broiler live performance, gizzard development, litter characteristics, and colon bacterial profiles.

In order to explain the observation that dietary 50% CC inclusion decreased feed intake in Chapter 3, experiment 4 was conducted by providing same crumble starter diet and whole pellet grower and finish diet, which removed the confounding effects of different GIT development factors during the early growth period by pellet quality on feed intake. Broiler live performance, GIT development, apparent ileal digestibility (AID) of energy and nitrogen, litter characteristics, and intestinal morphology were also reported.

In chapter 5, a 45 d cage study investigated the effects of three dietary CC inclusions on broiler live performance and apparent ileal digestibility (AID) of energy and nitrogen. The gizzard, proventriculus, and intestinal section development, and digesta, pH, retention time, and particle size distribution were measured to help explain the GIT motility, development, and function change by dietary CC inclusion.

Experiment 6 investigated the effects of two dietary CC inclusion levels and three different floor types on broiler live performance, litter characteristics, GIT development, apparent ileal digestibility of energy and nitrogen, intestinal morphology, and ammonia emission. Corn grinding cost by hammermill and roller mill was also compared.

The results of the experiments in this dissertation are discussed and summarized in Chapter 7.

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CHAPTER 2

Effects of Feed Form and Dietary Coarsely Ground Corn on Broiler Live Performance, Body Weight Uniformity, Relative Gizzard Weight, Fecal Nitrogen, and Particle Size Preference Behaviors

ABSTRACT

In this 14 d cage study, the effects of feed form and dietary coarsely ground corn (CC) inclusion on broiler live performance, BW uniformity, relative gizzard weight, fecal nitrogen, and particle size preference behaviors were investigated. This study was a 2 × 6 factorial arrangement of two feed forms (mash and pellet-crumble) and six dietary CC inclusions (0, 10, 20, 30, 40, and 50% CC that replaced fine corn (FC)). The geometric mean diameter by mass (dgw) of mash diets increased from 422 to 431, 471, 509, 542, and 640 μm, respectively, as 0, 10, 20, 30, 40, and 50% CC replaced FC. Interactions were observed for feed intake (FI) ($P < 0.05$), BW ($P < 0.01$), and relative gizzard weight ($P < 0.01$) at 14 d of age, and AdjFCR at 7 d of age ($P < 0.01$) between feed form and dietary CC inclusion. Crumble diet form increased FI, BW, and feed efficiency at 7 and 14 d of age ($P < 0.01$), increased fecal nitrogen ($P < 0.01$), improved BW uniformity ($P < 0.01$), and decreased relative gizzard weight ($P < 0.01$) at 14 d of age compared with birds fed the mash diet form. The dietary CC inclusion linearly decreased FI ($P < 0.01$) and BW ($P < 0.01$), and feed efficiency ($P < 0.05$) at 7 or 14 d of age, and linearly increased relative gizzard weight ($P < 0.01$) at 14 d of age. The birds exhibited particle size preference behaviors at 7 d of age in both feed forms. It was concluded that particle size was more critical in a mash diet than in a crumble diet with respect to the interaction effects of CC inclusion in the two feed forms. It was also concluded that CC inclusion stimulated gizzard development and influenced particle size preference behaviors.

INTRODUCTION

The importance of physical structure of the diet as a tool to improve broiler live performance, especially feed efficiency, has become increasingly recognized by the poultry industry. It has been previously thought that finely ground ingredients would enhance nutrient utilization and growth efficiency due to greater surface area being available for digestive enzymes and improved pellet quality (Behnke, 2001). However, broilers have an instinctive preference for coarse feed particles, and it has been reported that coarse feed particles enhanced gizzard function, which has been referred to as the pacemaker of gut motility (Ferket, 2000). The successful application of whole wheat in the EU poultry industry demonstrate that coarse-ground corn could be included into broiler diets to improve gut health and feed efficiency in the U.S. poultry system (Preston et al., 2000; Plavnik et al., 2002; Rodgers et al., 2012).

The positive effects of dietary inclusion of coarsely ground corn (CC) has been reported in several studies under certain circumstances (Nir et al., 1995a; Amerah et al., 2007), but inconsistency in results are apparent. Reece et al. (1985) reported that birds fed a 50% CC inclusion diet (814 µm dgw) performed better than those fed a medium ground corn pellet that had a similar dgw. However, Lott et al. (1992) found that broilers fed pellets with CC (1196 µm dgw) had a significantly lower BW gain and poorer feed efficiency at 21 d when compared with those fed pellets with 679 µm FC. The feed form, average particle size and distribution, and the ability of young broilers to utilize coarse particles could be confounding factors that cause inconsistent growth performance results. Therefore, a better understanding of the interactions between feed form, corn particle sizes, gizzard development, and live performance during the starter period is necessary to optimize broiler live performance.

The objectives of current study were to evaluate the effects of CC inclusion in two different feed forms on broiler live performance, BW uniformity, relative gizzard weight, fecal nitrogen, and particle size preference behaviors during the starter period.

MATERIAL AND METHODS

Feed Formulation, Manufacture, and Experiment Design

Corn-soy broiler diets (Table 2-1) were formulated and manufactured at the North Carolina State University Feed Mill Education Unit to meet or exceed the NRC suggested minimum requirements of broilers (NRC, 1994). The six CC treatment starter diets were produced by replacing 0, 10, 20, 30, 40, and 50% FC by CC. The FC and soybean meal were ground with a hammermill (Model 1522, Roskamp Champion, Waterloo, IA) equipped with two 2.4 mm screens, while the CC was ground with a two-pair roller mill (Model C128829, RMS, Tea, SD) with a gap setting of 0% opening on top and 100% opening on bottom. Dry ingredients were blended in a double ribbon mixer (TRDB126-0604, Hayes & Stolz Ind. Mfg. Co., Fort Worth, TX) to produce six mash diets. Half of each mash diet was conditioned to 85°C and pelleted with a pellet mill (Model PM1112-2, California Pellet Mill Co., Crawfordsville, IN) equipped with a ring die (4.4 mm by 35 mm). Pellets were cooled with ambient air in a counter-flow cooler (Model VK09 × 09KL, Geelen Counterflow Inc., Orlando, Florida), and then crumbled. Particle size distribution was determined by ASAE S319.3 and the pellet durability index was determined by ASAE standard S269.4.

Husbandry Practices

The care of the birds in the study conformed to the Guide for Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010). A total of 864 Ross 344 × 708 (Aviagen, Huntsville, AL) 1-d-old male broiler chicks were feather sexed, weighed, and placed in two environmentally controlled rooms. Each room was considered as a block, which housed four Petersime batteries that had 12 cages distributed over 6 decks. On the day of hatch, 9 chicks were assigned per pen with 96 pens in total. Care was taken to distribute incubator tray position uniformly among all of the broiler pens. Each cage was 70 cm in width, 100 cm in length, and 30 cm in height, and was equipped with 1 trough feeder and 1 trough drinker. Feed and water were provided for *ad libitum* consumption. Each cage was randomly assigned to 1 of 12 treatments (two feed forms, mash or crumble, and six CC inclusions, 0, 10, 20, 30, 40, or 50%) with a total of 8 replicates per interaction. There was 0.9 kg of feed/chick budgeted from 0 to 14 d of age. The lighting program consisted of 23 h of light and 1 h of darkness for the 14 d experimental period. The room temperature was 35°C from 1 to 2 d, 32 to 33°C from 3 to 7 d, 30 to 32°C from 8 to 14 d.

Data Collection

Initial pen group BW was collected at placement. Feed intake by cage and individual BW were recorded at 7 and 14 d of age. Individual BW uniformity was expressed as the CV of BW, which was equal to standard deviation/mean × 100%. Birds were observed twice daily and mortalities were removed and weighed to calculate adjusted FCR (AdjFCR). At 7 d of age, feeders were emptied and fresh feed was added. Feed remaining in each feeder 6 h later was collected. The particle size distribution of the remaining mash diets was determined by ASAE S319.3. The remaining crumble diets were separated by passing #10 (2000 μm) screen as fines leftover (pass #10 screen) and crumbles leftover (above #10 screen). Nitrogen of these fines and crumbles was determined by Nitrogen Combustion Analysis (Method 990.03, AOAC, 2006). At 14 d of age all the birds in one room were individually weighed, killed by cervical dislocation, and the gizzard excised. The fat surrounding the gizzard was trimmed, contents removed, rinsed, blotted dry, then weighed and expressed as a percentage of BW (mg/g BW). Fresh feces were collected continuously for 3 d (14 to 16 d of age), mixed, and nitrogen content determined.

Statistical Analysis

The data was analyzed as a 2 × 6 factorial randomized complete block design to determine main effects and interactions, two feed forms (mash or crumble) and six CC inclusions (0, 10, 20, 30, 40, or 50%), with rooms that housed four Petersine batteries as blocks. The cage served as the experimental unit for the statistical analysis of the live performance data. All data were analyzed using PROC GLM of the SAS program (Version 9.1, SAS Institute Inc., Cary, NC). Differences were considered significant at $P < 0.05$ or $P < 0.01$, and the differences between means were separated by least significant difference. Orthogonal contrasts comparisons were conducted to determine the linear, quadratic or cubic effects of CC inclusion.

RESULTS AND DISCUSSION

The geometric mean diameter by mass (dgw) and particle size distribution of FC, CC, and mash diets prior to pelleting with 0, 10, 20, 30, 40, and 50% CC are shown in Figures 2-1 and 2-2. The dgw of FC and CC was 229 and 1642 μm, respectively, and as the 0, 10, 20, 30, 40, or 50% CC replaced FC in the diets, the dgw of mash diets was 422, 431, 471, 509, 542, or 640 μm, respectively. The FC and CC exhibited a different particle size distribution, and by mixing them the mash diets exhibited two majority particle domains, which peaked at 1600 and 500 μm. Feed particle size was envisioned to have a paradoxical role in poultry digestion. Traditionally, fine particles with greater relative surface area are thought to benefit better enzymatic digestion and absorption. In contrast, coarse particles stimulate gizzard function and enhance gastrointestinal tract motility, resulting in increased digestive efficiency.

The hammermill and roller mill have been two commonly used grinding devices to reduce the particle size of feed grains. Hammermill grinding has created a more uniform particle size distribution and roller mill grinding has created a more concentrated particle size distribution (Nir et al., 1995). By mixing we produced a biphasic distribution of particle size, the smaller particles for better nutritional digestion and absorption and larger particles to stimulate gizzard function.

The interaction effects of feed form and CC inclusions on feed intake, BW, BW uniformity, AdjFCR, fecal nitrogen, and relative gizzard weight at 7 and 14 d of ages are shown in tables 2-2 and 2-3. The interactions of CC inclusion and feed form were observed on 14 d feed intake ($P < 0.05$), 14 d BW ($P < 0.01$), 7 d AdjFCR ($P < 0.01$), and 14 d relative gizzard weight ($P < 0.01$), as well as differences that approached significance for 14 d AdjFCR ($P = 0.07$) and 14 d fecal nitrogen ($P = 0.06$). Interactions between grain particle size and feed form for broiler feed intake and BW have been well documented (Hamilton and Proudfoot, 1995; Nir et al., 1995b; Svihus et al., 2004; Peron et al., 2005). Douglas et al. (1990) reported that inclusion of CC (1470 dgw to1800 μm) in mash diet depressed BW gain and feed efficiency as compared with FC (833 to 947 μm dgw). Reece et al. (1986) found that there was no effect of corn particle size on live performance in crumble form. Amerah et al. (2007) concluded that grain particle size was more critical in mash diets than in pelleted or crumble diets. These interaction effects between feed form and corn particle size may be explained by the instinctive preference for coarser feed particles of the broiler, and that there was less opportunity for selection of particles of different sizes (Reece et al., 1986), which supported a better balanced nutrient intake.

The main effects of feed form on feed intake, BW, BW uniformity, AdjFCR, fecal nitrogen, and relative gizzard weight are shown in Tables 2-2 and 2-3. Broilers fed a crumble diet had significantly increased feed intake ($P < 0.01$) and BW ($P < 0.01$), and improved AdjFCR ($P < 0.01$) at both 7 and 14 d of age as compared to birds fed mash diets. The crumble diet also improved BW uniformity ($P < 0.01$), increased fecal N ($P < 0.01$), and decreased relative gizzard weight at 14 d of age ($P < 0.01$). The improved live performance and efficiency observed among birds fed the crumbled diet in comparison to those fed the mash diets has been reported in many studies. Amornthewaphat et al. (2005) reported a similar result that broilers fed crumble diets exhibited significantly greater feed intake ($P < 0.01$) than those fed mash diets at 21 d of age. AdjFCR of crumble diet was also improved ($P < 0.01$), which was consistent with the observations of Hamilton et al. (1995). Greater feed intake to compensate for the greater energy required for prehension may explained these main effects of feed form on live growth performance. The birds fed a crumble diet had better BW uniformity, thus homogeneity of feed form may improve broiler BW uniformity. Pellet or crumble diet forms may decrease broiler selective feeding behavior due to better feed integrity as compared with mash feed form. The increased fecal nitrogen excretion among birds fed the crumble feed form treatment may be due to greater feed intake as compared to those fed the mash treatment. However, feed intake among broilers fed the crumbled feed was improved 19.0% over those fed the mash diets (797 versus 670 g), and fecal nitrogen was only increased 2.5% (3.23 versus 3.15 %), which suggested nitrogen utilization was improved by the crumble feed form. The birds fed mash feed had heavier relative gizzard weight (2.3 versus 1.8%) as the consequence of larger absolute gizzard weight in these small BW birds, which was consistent with pervious results (Nir et al., 1995; Svihus et al., 2004; Parsons et al., 2006). Nir et al. (1995) observed that pelleting resulted in a decrease in the relative gizzard weight when mash and pellet diets were compared. Svihus et al. (2004) concluded that pelleting compressed particle size distribution, which decreased the average particle size in a pelleted diet, and reduced the response of gizzard to the CC in a crumble diet.

The main effects of dietary CC inclusion on feed intake, BW, BW uniformity, AdjFCR, fecal nitrogen, and relative gizzard weight, and its orthogonal contrast comparisons are also shown in Tables 2-2 and 2-3. The CC inclusion linearly decreased feed intake ($P < 0.01$), BW ($P < 0.01$), AdjFCR ($P < 0.05$), and relative gizzard weight ($P < 0.01$) at 7 and 14 d. Reduced live performance, such as lower feed intake and BW, and higher AdjFCR, coincident with the increased proportion of the dietary CC suggested that young broilers may not be able to efficiently consume or utilize larger corn particles due to an underdeveloped grinding capacity of the gizzard (Lott et al., 1992; Kilburn et al., 2001). The linear increase in relative gizzard weight at 14 d of age corroborated the results of Olver and Jonker (1997) and Dahlke et al. (2003); gizzard weight increased with greater corn dgw, independent of the physical form of the diet. Parsons et al. (2006) reported that absolute and relative gizzard weight increased as corn particle size increased from 781, 950, 1,042, 1,109, to 2,242 µm. The gizzard is the key gastric organ to reduce coarse particles to smaller size for improved digestive efficiency, and a large, well-developed gizzard is involved with the regulation of gut motility (Ferket, 2000). While the gizzard reduces digesta pH and passage rate (Nir et al., 1994), it enhances enzymatic digestion efficiency, and improves energy utilization and nutrient digestibility (Duke, 1992; Amerah et al., 2007).

The results of particle size preference are shown in Figure 2. 4. The selective feeding behavior was apparent even at 7 d of age in both feed forms, which was indicated by dgw or nitrogen (N) content changes in mash or crumble forms, respectively. In mash diets, increased dietary CC inclusion decreased dgw after 6 h of feeding. In crumble diets, the N of fine particles tended to increase and the N of crumble particles tended to decrease, which indicated that chicks were not consuming a homogeneous mix of ingredients due to coarser particle preference. Poultry have been reported to have a preference for larger feed particles (Schiffman, 1968), and birds can distinguish the differences in feed particle size by mechanical sensors located in the beak (Gentle, 1979), which has been observed at all ages (Portella et al., 1988). It was logical that birds have more opportunity to choose coarse particles when consuming a mash diet than when consuming a pelleted diet. A possible reason for the N change in the crumbled diet may be because more yellow chunks of corn are available to be chosen by the chicks, and fines contain more N than in coarser particles. The selective feeding behavior observed in this study help explain the interaction effects observed on live performance differences due to feed form, particle size, and gizzard size as discussed above. Clark et al. (2009) reported that selective feeding could be a reason for a linear decrease in growth response as the proportion of CC increased in the diet.

The results of this study confirmed our hypothesis that chicks respond differently to feed particle size in mash and crumble diets, as evidenced by the observed interaction effects on broiler live performance and BW uniformity. Further, dietary CC inclusion stimulated gizzard development and encouraged selective feeding behavior.

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Table 2-1. Ingredient composition and calculated analysis for broiler starter diet

Item	%
Ingredient	
Corn	59.30
Soybean meal, 48% CP	35.80
Limestone	2.09
Dicalcium phosphate, 18% P	0.97
DL-Methionine	0.00
L-Lysine	0.19
L-Threonine	0.05
Sodium chloride	0.50
Vitamin premix[1]	0.05
Choline chloride, 60%	0.20
Trace mineral premix[2]	0.20
Selenium premix[3]	0.10
Coccidiostat[4]	0.05
Poultry fat	0.50
	100.00
Calculated analysis	
ME, kcal/g	2.94
Protein, %	23.00
Calcium, %	0.90
Available phosphorus, %	0.45
Total lysine, %	1.26
Total methionine +cysteine, %	0.96

[1] The vitamin premix supplied the following per kg of feed: vitamin A, 6601; cholecalciferol, 1980 IU; niacin, 55 mg; α-tocopheral, 33 mg; pantothenic acid 11 mg; riboflavin, 6.6 mg; pyridoxine, 4 mg; menadione, 2 mg; thiamin, 2 mg; folic acid, 1.1 mg; biotin, 0.13 mg; and vitamin B12, 0.02 mg.

[2] The mineral premix supplied the following per kg of feed: Zn, 120 mg; Mn, 120 mg; Fe, 80 mg; Cu, 10 mg; I, 2.5 mg; Co, 1.0 mg.

[3] Selenium premix provided 0.2 ppm Se.

[4] Monensin was included at 99 mg/kg (Coban 90, Elanco Animal Health, Indianapolis IN, USA).

Table 2-2. Effect of feed form and CC on feed intake, BW and BW uniformity expressed as CV, from 0 to 14 d of age

			Feed Intake		BW		CV	
Feed Form[1]	CC[1]	n	7 d	14 d	7 d	14 d	7 d	14 d
Interaction				(g/bird)			(%)	
Mash	0%	8	168	679	176	561	10.0	11.8
Mash	10%	8	164	706	174	545	12.4	11.9
Mash	20%	8	162	683	171	555	11.0	10.1
Mash	30%	8	162	674	172	544	13.5	12.5
Mash	40%	8	151	640	156	495	12.9	12.0
Mash	50%	8	151	641	159	505	11.8	10.4
Crumble	0%	8	183	784	204	652	10.0	8.1
Crumble	10%	8	182	799	201	667	10.3	7.5
Crumble	20%	8	182	816	206	672	13.6	10.9
Crumble	30%	8	174	785	196	655	12.8	8.8
Crumble	40%	8	178	799	200	674	13.5	9.1
Crumble	50%	8	173	799	192	659	12.8	9.6
	SEM		3.7	11.4	3.7	9.2	1.3	1.1
Main Effects								
Mash		48	160^{B}	670^{B}	168^{B}	534^{B}	11.9	11.4^{A}
Crumble		48	179^{A}	797^{A}	200^{A}	663^{A}	12.1	9.0^{B}
SEM			1.5	4.7	1.5	3.7	0.5	0.4
	0%	16	175^{A}	731^{ABC}	190^{A}	607^{AB}	10.0	9.9
	10%	16	173^{AB}	753^{A}	187^{AB}	606^{ABC}	11.3	9.7
	20%	16	173^{AB}	750^{AB}	189^{A}	613^{A}	12.3	10.5
	30%	16	168^{ABC}	729^{ABC}	184^{ABC}	599^{ABC}	13.1	10.6
	40%	16	165^{BC}	719^{C}	178^{BC}	585^{BC}	13.2	10.6
	50%	16	162^{C}	720^{BC}	175^{C}	582^{C}	12.3	10.0
	SEM		2.6	8.1	2.6	6.5	0.9	0.8
Source of variation					*P-value*			
CC * Feed Form			0.39	< 0.05	0.10	< 0.01	0.56	0.14
Feed Form			< 0.01	< 0.01	< 0.01	< 0.01	0.76	< 0.01
CC			< 0.01	< 0.05	< 0.01	< 0.01	0.13	0.93
Contrast								
Linear			< 0.01	< 0.01	< 0.01	< 0.01	0.32	0.71
Quadratic			0.49	0.07	0.29	0.08	0.46	0.82
Cubic			0.79	0.02	0.98	0.21	0.97	0.99

$^{a-c}$ Means within a column with different superscripts differ significantly ($P \leq 0.05$).

$^{A-B}$ Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of mash or crumble diets with 0, 10, 20, 30, 40, or 50% CC inclusion.

Table 2-3. Effect of feed form and CC on adjusted feed conversion ratio (AdjFCR), fecal nitrogen (N), and relative gizzard weight from 0 to 14 d of age

			AdjFCR		Fecal N	Gizzard
Feed Form[1]	CC[1]	n	7 d	14d	14 d	14 d
Interaction			(g of feed/g of BW gain)		(%)	(mg:g)
Mash	0%	8	1.27	1.32	3.03	2.00
Mash	10%	8	1.26	1.41	3.14	2.10
Mash	20%	8	1.28	1.33	3.15	2.14
Mash	30%	8	1.28	1.36	3.14	2.29
Mash	40%	8	1.37	1.42	3.14	2.52
Mash	50%	8	1.31	1.39	3.27	2.54
Crumble	0%	8	1.13	1.29	3.25	1.75
Crumble	10%	8	1.20	1.30	3.28	1.82
Crumble	20%	8	1.14	1.29	3.25	1.82
Crumble	30%	8	1.17	1.29	3.25	1.87
Crumble	40%	8	1.14	1.28	3.22	1.89
Crumble	50%	8	1.17	1.30	3.14	1.88
	SEM		0.02	0.02	0.06	0.05
Main Effects						
Mash		48	1.29^{A}	1.37^{A}	3.15^{A}	2.26^{A}
Crumble		48	1.16^{B}	1.29^{B}	3.23^{B}	1.84^{B}
SEM			0.01	0.01	0.02	0.02
	0%	16	1.20^{b}	1.30^{c}	3.14	1.88^{C}
	10%	16	1.23^{ab}	1.35^{a}	3.21	1.96^{BC}
	20%	16	1.21^{ab}	1.31^{bc}	3.20	1.98^{BC}
	30%	16	1.22^{ab}	1.33^{abc}	3.19	2.08^{AB}
	40%	16	1.25^{a}	1.35^{a}	3.18	2.21^{A}
	50%	16	1.24^{a}	1.35^{ab}	3.20	2.21^{A}
	SEM		0.01	0.01	0.04	0.04
Source of variation			*P-value*			
CC * Feed Form			< 0.01	0.07	0.06	< 0.01
Feed Form			< 0.01	< 0.01	< 0.01	< 0.01
CC			0.16	< 0.05	0.82	< 0.01
Contrast						
Linear			0.02	< 0.05	0.52	< 0.01
Quadratic			0.95	0.94	0.51	0.90
Cubic			0.89	0.35	0.27	0.33

[a-c] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

[A-B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of mash or crumble diets with 0, 10, 20, 30, 40, or 50% CC inclusion.

Table 2-4. The Influence of feed form and CC inclusion on broiler selective feeding behaviors at 7 d of age

CC	Dgw * of Mash Diet			Crude Protein of Crumble Diet			
	Before Feeding	After 6 h Feeding	Difference	Before Feeding	After 6 h Feeding		
					Fines (< 2mm)	Crumble (> 2mm)	Difference
(%)	(µm)	(µm)		%	%	%	
0	422	436	14	22.78	21.91	25.24	3.33
10	431	401	30	23.12	22.45	24.54	2.09
20	471	377	94	23.19	23.11	24.48	1.37
30	509	360	149	23.43	22.84	23.67	0.83
40	542	354	188	23.45	23.28	24.20	0.92
50	640	357	283	22.96	23.64	22.86	-0.78

*Dgw=geometric mean diameter by mass

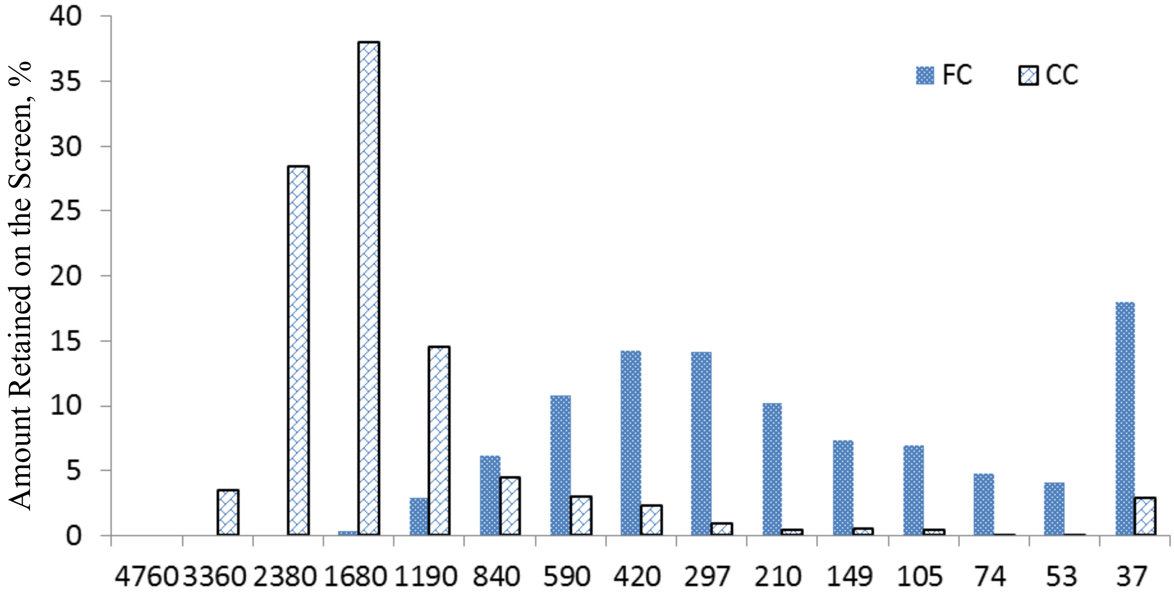

Figure 2-1. Descriptive data of the particle size distribution of fine corn (FC) and coarse corn (CC) prior to mixing

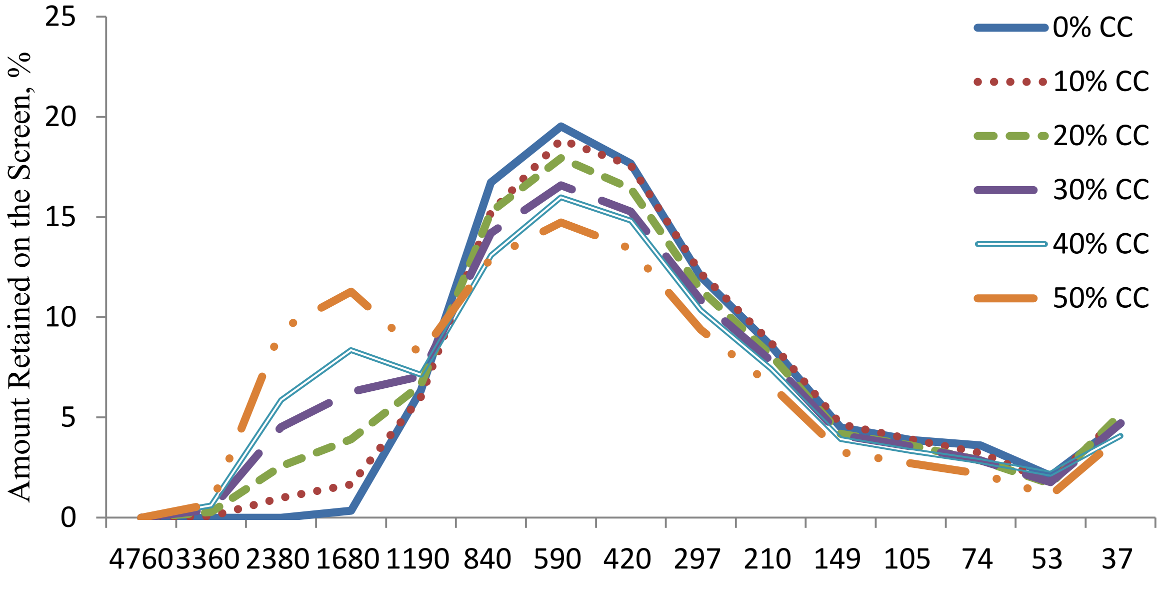

Figure 2-2. Descriptive data of the particle size distribution of mash diets with different coarse corn (CC) inclusions

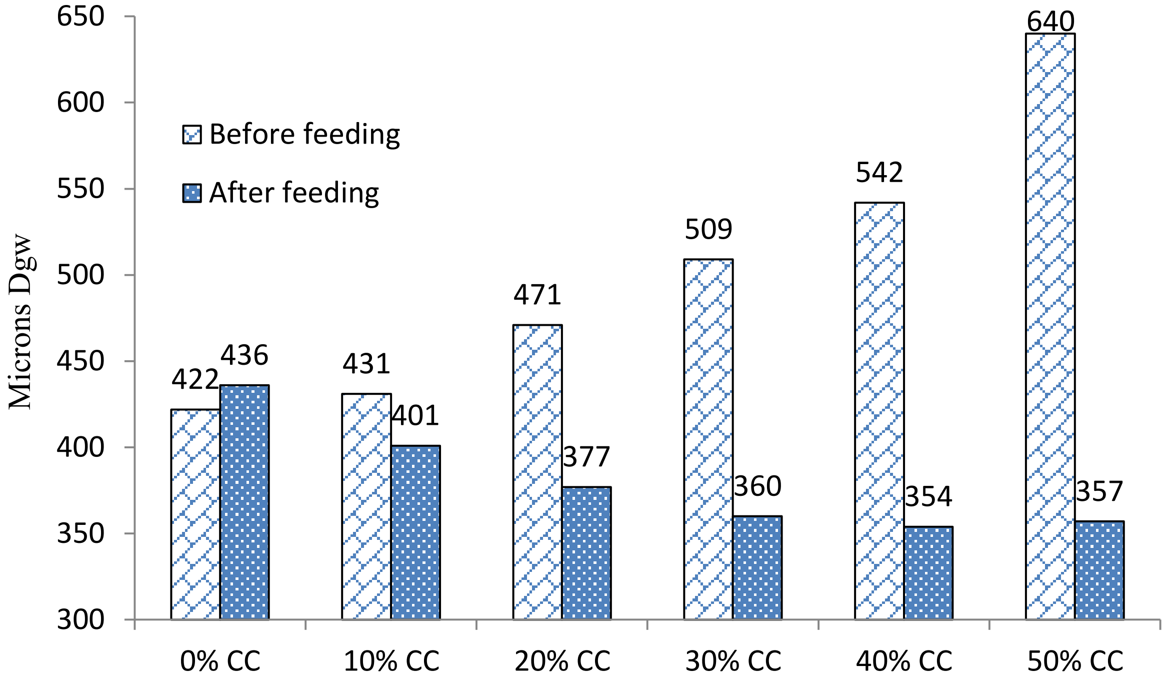

Figure 2-3. Descriptive data of the selective feeding behavior in mash diet as indicated by feed dgw change after 6 h feeding

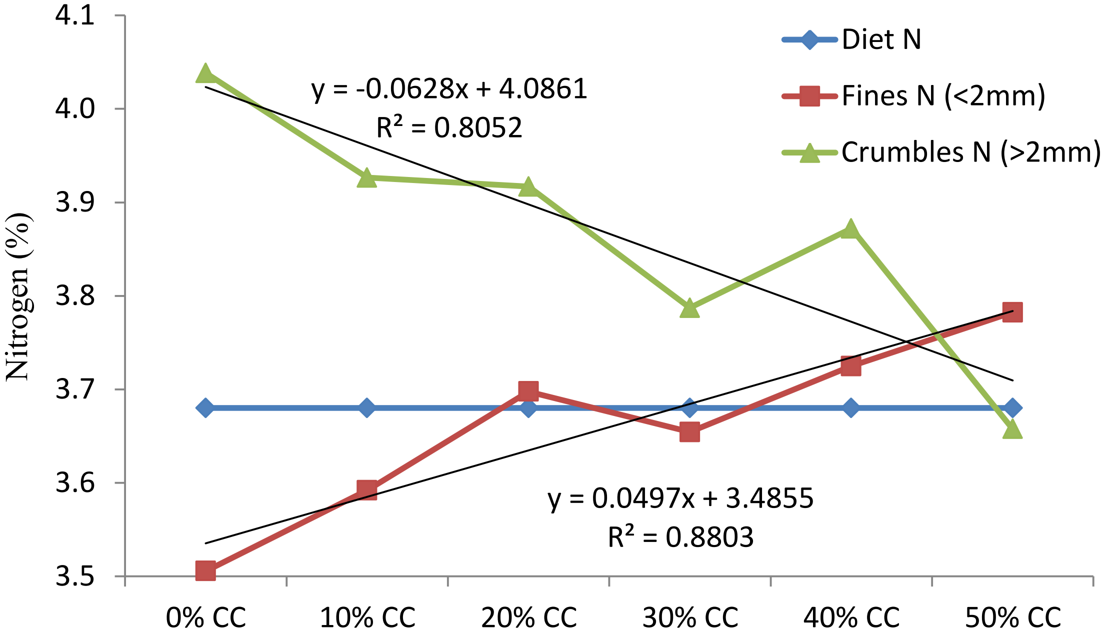

Figure 2-4. The selective feeding behavior in crumbled diet, as indicated by feed nitrogen difference after 6 h feeding

CHAPTER 3

Evaluation of Gender, Litter Type and Dietary Coarsely Ground Corn Inclusion on Broiler Live Performance, Gastrointestinal Tract Development, Litter Characteristics, and Colon Bacterial Profiles

ABSTRACT

Two 49-d floor pen studies were conducted to evaluate the effects of gender, litter type, and dietary inclusion of coarsely ground corn (CC) on broiler live performance, gastrointestinal tract (GIT) development, litter characteristics, and colon bacterial profiles. Experiment 1 was a 2 × 2 factorial arrangement of 2 genders (male or female) and 2 CC levels (0 or 50%). The only interaction observed was on feed intake and BW gain from 14 to 35 d, where the addition of CC decreased feed intake ($P < 0.01$) and BW gain ($P < 0.05$). Dietary inclusion of CC decreased feed intake ($P < 0.01$) and BW gain ($P < 0.05$) before 35 d, and improved adjusted feed conversion ratio (AdjFCR) from 35 to 49 d ($P < 0.05$). Male broilers exhibited better live performance than females during the whole period, such as higher feed intake ($P < 0.01$) and BW gain ($P < 0.01$), and improved AdjFCR ($P < 0.01$), but with greater mortality ($P <0.05$). Dietary inclusion of CC increased relative gizzard weight ($P < 0.01$), and decreased relative proventriculus weight ($P < 0.01$) at 49 d. Experiment 2 was a 2 × 2 factorial arrangement of 2 dietary levels of CC (0 or 50%) and 2 litter types (finely ground old litter or new wood shavings litter). No treatment interaction effects were observed. Dietary inclusion of CC decreased feed intake throughout the experiment without affecting final BW, and improved AdjFCR after 25 d ($P < 0.01$). New litter improved AdjFCR from 1 to 14 d ($P < 0.05$). At 49 d, the birds fed the CC diet had lower fecal N ($P < 0.05$) and litter moisture ($P < 0.05$), and exhibited greater numbers of Firmicutes ($P < 0.05$) and lower numbers of Proteobacteria ($P < 0.05$) on the phylum level, as well as lower numbers of Enterobacteriaceae ($P < 0.05$) on the family level in the colon. In conclusion,

50% CC inclusion increased relative gizzard weight, improved AdjFCR, reduced fecal N, and altered colon microflora towards a more symbiotic bacterial profile, while new litter had only a marginal benefit on broiler live performance.

INTRODUCTION

Different strategies have been explored to improve broiler live growth performance and feed efficiency. Structural dietary components, such as wheat (Engberg et al., 2004; Biggs et al., 2009), sorghum (Rodgers et al., 2012), coarsely ground corn (Lott et al., 1992; Amerah et al., 2008), and dietary fiber (Gonzales-Alvarado et al., 2007, 2008) have been shown to improve broiler growth performance and feed efficiency under certain circumstances. The gizzard obviously plays a key role in this strategy, and its development and function interacts with structural material intake through gastric muscle contraction and sheer. It has been clearly established that consumption of coarse material improves gizzard development. Dietary inclusion of coarsely ground corn (CC) has been recognized as a practical method in typical U.S. corn-soybean meal diets, whereas coarse ground or whole wheat or sorghum in the EU, Australia, or Canada. However, the optimal dietary inclusion level of CC or optimal corn particle size distribution in broiler diet has not been established.

The gizzard has been found to have a very unique role in broiler gastrointestinal tract (GIT) function. The typical function of the gizzard has been reported to be as a gastric grinder for mechanical particle size reduction (Duke, 1992), which may stimulate and synchronize GIT motility as a result (Ferket, 2000). The gizzard regulates digesta flow through reverse peristalsis (Clench and Mathias, 1992; Jimenez et al., 1994). Svihus (2002) reported that enhanced gizzard activity increases digesta retention time, possibly improves nutrient digestibility (Samu et al., 2010), and changes the colon bacterial profile (Engberg et al., 2004). Due to the close interaction between the proventriculus and gizzard, it has been reported repeatedly that consumption of structural material decreased pH of the gizzard contents by 0.2 and 1.2 units (Gabriel et al., 2003; Engberg et al., 2004; Jimenez-Moreno et al., 2009; Senkoylu et al., 2009), with potential benefits regarding enzymatic digestion and gut health.

The insoluble fiber found in barley, oats, and soybean meal has been shown to influence GIT function through enhanced gizzard activity (Svihus et al., 2001), with increased digesta retention time (Hetland et al., 2002, 2003) , increased hydrochloric acid production by the proventriculus (Duke, 1986), and improved starch digestibility (Hetland and Svihus, 2001). Meanwhile, litter could be another significant source of insoluble fiber that has been often ignored, as limited information has been reported regarding the effect of litter fiber on broiler performance. However, Hetland et al. (2003) reported that the weights of empty gizzard and gizzard contents were increased due to access to typical wood shavings used as litter.

The objectives of the current study were to evaluate the effect of gender, litter type, and dietary CC inclusion on 49-d broiler live performance, gizzard and proventriculus weight, litter characteristics, and colon bacterial profiles.

MATERIALS AND METHODS

Feed Formulation, Manufacture, and Experiment Design

Corn-soy broiler diets (Table 3-1) were formulated and manufactured at the North Carolina State University Feed Mill Education Unit to meet or exceed the NRC suggested requirements of broilers (NRC, 1994). The two CC treatment diets were produced by replacing 0 or 50% of fine corn (FC) with CC. The FC and soybean meal were ground with a hammermill (Model 1522, Roskamp Champion, Waterloo, IA) equipped with two 2.4 mm screens, while the CC was ground with a two-pair roller mill (Model C128829, RMS, Tea, SD) with a gap settings of 0% opening on the top and 100% opening on the bottom. Dry ingredients were blended in a double ribbon mixer (TRDB126-0604, Hayes & Stolz Ind. Mfg. Co., Fort Worth, TX) to produce the mash diets that were conditioned at 85°C for 45 seconds and then pelleted with a ring die (4.4 mm by 35 mm) pellet mill (Model PM1112-2, California Pellet Mill Co., Crawfordsville, IN). Pellets were cooled with ambient air in a counter-flow cooler (Model VK09 × 09KL, Geelen Counterflow USA Inc., Orlando, Florida). The starter feed was provided as crumbles to 14 d, and subsequent grower and finisher feeds were fed as pellets. Particle size distribution was determined by ASAE S319.3 and the pellet durability index was determined by ASAE standard S269.4.

Husbandry Practices

Two experiments were conducted at the North Carolina State University Chicken Educational Unit. The care of the birds in these studies conformed to the Guide for Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010). In Experiment 1, a total of 1,152 Ross 344 x 708 (Aviagen, Huntsville, AL) 1-d-old male and female broiler chicks were feather sexed, weighed, and placed in a curtain-sided, heated, and fan-ventilated broiler house until 49 d of age. On the day of hatch 18 chicks were randomly assigned per pen with 72 pens in total. Each side of 36 pens was considered a block. Each pen was 1.2 m width by 3.8 m length, and the stocking density was 4 chicks/m^2. Each pen contained one bell-type drinker and two tube feeders. Each pen was assigned to one of four factorial treatments (male or female and 0 or 50% CC diet) with 18 replicates per interaction. The chicks were given a budget of 0.9, 2.7, and 3.6 kg starter, grower, and finisher feeds, respectively. The birds were raised on used litter that was top-dressed with new wood-shavings at the start of the study. The birds had *ad libitum* access to water and feed throughout the study. Feeders were shaken once per day from 1 to 14 d and twice per day from 15 to 49 d to minimize variation in feed intake due to feed flow characteristics. The lighting program started with 23 h of light from 1 to 7 d, 22 h of light to 14 d, 20 h of light to 21 d, and natural light from 22 to 49 d of age. The temperature of the house from placement to 7 d was maintained at 32 to 34°C, 29°C to 14 d, 27°C to 21 d, and ambient thereafter.

In Experiment 2, 1,024 Ross 344 × 708 d-old male broiler chicks were feather sexed and randomly placed into 32 pens with 32 chicks per pen. Each pen was 1.2 m wide by 3.8 m long. The stocking density was 7 chicks/m^2. Each pen was randomly assigned to one of four factorial treatments (fine ground old litter or new wood shavings and 0 or 50% CC). The feeding and lighting practices were the same as in Experiment 1.

Data Collection

In Experiment 1, initial pen BW was collected at placement. Feed intake and BW by pen were thereafter recorded at 14, 35, and 49 d of age. Birds were observed twice daily and mortalities were removed and weighed to calculate AdjFCR. At 49 d of age, one half of the birds were individually weighed and the gizzard excised. The surrounding fat was trimmed, organ contents removed, rinsed, blotted dry, and then weighed and expressed as a percentage of BW (mg/g BW). Digesta was collected from the colon and ileum junction and stored at -80ºC until used to determine colon bacterial profile. The QIAamp Stool DNA Mini Kit (Qiagen, Valencia, CA) was used to isolate bacterial DNA from a 225 mg sample of digesta. DNA samples were assessed for differences in bacterial populations through the use of the terminal restriction fragment length polymorphism (TRFLP) procedure performed by the Microbiome Core Facility (University of North Carolina, Chapel Hill) (Liu et al., 1997). Fragments generated were then assigned to microbial phylogenies using the Phylogenetic Assignment Tool (Angela et al., 2003).

In Experiment 2, feed intake and BW by pen were recorded at 14, 28, 42, and 49 d of age. Fresh litter samples were taken from six positions within each pen and mixed to create a composite sample for each pen. Litter moisture, pH, and nitrogen (N) content were determined for each pen sample. Moisture was determined by loss on drying at 95 to 100°C (Method 934.01, AOAC, 2006a), and the pH of the gizzard and proventriculus digesta was measured with a portable pH meter (HACH IQ150 pH/mV/Temperature System). Litter N content was determined by Nitrogen Combustion Analysis (Method 990.03, AOAC, 2006b).

Statistical Analysis

Both experiments were analyzed as a 2 × 2 factorial randomized complete block design to determine main effects and interactions. Experiment 1 was a 2 × 2 factorial arrangement of 2 genders (male or female) and 2 CC levels (0 or 50%). Experiment 2 was a 2 × 2 factorial arrangement of 2 litter types (finely ground old litter or new wood shavings litter) and 2 CC levels (0 or 50%). The pen served as the experimental unit for the statistical analysis of the live performance data. Mortality data were subjected to arcsine percentage transformation before analysis. All data except the colon bacterial profile were analyzed using PROC GLM of the SAS program (version 9.1, SAS Institute Inc., Cary). Differences between treatment means were separated by the least significant difference test. The pairwise t-test was used to test for difference in the bacterial populations. Differences were considered significant at $P < 0.05$ unless otherwise indicated.

RESULTS AND DISCUSSION

The geometric mean diameter by mass (dgw) and particle size distribution of FC, CC, soybean meal, and mash diets prior pelleting with 0 or 50% CC replaced FC are shown in Figures 3-1 and 3-2. The dgw of FC, CC, and soybean meal was 227, 1190, and 491 μm, respectively. As the 0 and 50% CC replaced FC in the diets, the dgw of mash diets prior to pelleting were 432 and 640 μm, respectively. The hammermill and roller mill are two commonly used grinding methods to reduce the particle size of the grains. Hammermill grinding creates a wider particle size distribution with greater efficiency for fine grinding. In contrast roller mill grinding creates a narrow particle size distribution and is more efficient for coarse grinding (Nir et al., 1995). By mixing corn ground by these two methods, we produced a biphasic particle size distribution with two frequency peaks; larger the particles were intended to stimulate gizzard function and smaller particles were intended to improve pellet quality, digestion and nutrient absorption. In comparison to the diets that contained 0% CC diet, pellet quality of 50% CC diets, as determined by Pellet Durability Index (PDI), decreased 5% in the grower diet (90 *versus* 85%) and by 6% in the finisher (85 *versus* 79%). Pellet durability has been found to be inversely related to particle size (Angulo et al., 1996) because smaller particles within a pellet have more potential contact points for particle agglomeration (Behnke, 2001). The decreased PDI observed in the current study was in agreement with the finding of Amerah et al. (2008), who reported that fine ground corn improved pellet durability as compared to CC.

For Experiment 1, the effects of gender and dietary CC inclusion on feed intake, BW gain, AdjFCR, and mortality of broilers from 0 to 49 d of age are shown in Tables 3-2 and 3-3. The only interaction effect observed was between gender and dietary CC inclusion during the 15 to 35 d period. Males broilers exhibited higher feed intake ($P < 0.01$) and BW gain than females ($P < 0.05$), but 50% CC inclusion decreased feed intake ($P < 0.01$) and BW gain ($P < 0.01$) only among males. This interaction suggested males and females require different dietary CC inclusion. The 50% CC inclusion decreased feed intake and BW gain in the 0 to 14 d, 15 to 35 d, and 0 to 49 d periods ($P < 0.01$), but there was no difference on feed intake and BW gain during the 35 to 49 d period. The only effect of 50% CC inclusion on

AdjFCR was observed in the 36 to 49 d period, where 50% CC improved AdjFCR ($P <$ 0.05).

Males had greater feed intake and BW gain than females during the entire study ($P <$ 0.01). There was no significant difference in AdjFCR during the 0 to 14 d period, and males exhibited better AdjFCR than females during 15 to 35 and 36 to 49 d periods ($P < 0.01$). Mortality of males was greater than the females ($P < 0.05$).

For Experiment 2, the effects of litter type and dietary CC inclusion on feed intake, BW gain, and AdjFCR from 0 to 49 d of age are shown in Tables 3-4 and 3-5. No treatment interaction was observed. Inclusion of 50% dietary CC decreased feed intake during the 0 to 14 d ($P < 0.01$), 15 to 28 d ($P < 0.01$), 43 to 49 d ($P < 0.05$), and 0 to 49 d ($P < 0.01$) periods, which consequently decreased BW gain in the 0 to 14 d ($P < 0.01$) and 15 to 28 d periods (P < 0.01). However, increased BW gain in the 29 to 42 d period ($P < 0.05$) without effect on BW gain in the 43 to 49 d resulted in no overall treatment effect on BW from 0 to 49 d periods. Consequently, the AdjFCR was improved by 50% dietary CC inclusion in the 29 to 42 d, 43 to 49 d, and 0 to 49 d periods ($P < 0.01$). The only litter type effect was observed during the 0 to 14 d period, as new litter decreased feed intake ($P < 0.01$) without influencing BW gain, which consequently improved AdjFCR ($P < 0.05$). No treatment effects were observed on mortality rates.

The effect of dietary CC inclusion on decreased feed intake and BW gain under certain circumstances agree with previous reports. Lott et al. (1992) found that broilers fed pelleted feeds that contained coarse hammermill ground corn (1196 μm dgw) had a significantly lower feed intake and BW gain at 21 d than those fed pellets containing more finely ground corn (679 µm dgw). Amerah et al. (2008) reported that feed intake of pelleted diets decreased ($P < 0.05$) when wheat or corn particle size increased (284 to 890 µm and 297 to 528 µm dgw, respectively). Decreased feed intake was thought to be related to poor CC utilization by younger broilers (Lott et al., 1992) and poorer pellet quality due to CC inclusion (Corzo et al, 2011; Lilly, 2011). Young broilers may not be able to efficiently consume or utilize larger corn particles due to an underdeveloped GIT. Improved AdjFCR was consistent with previous investigations. Kilburn and Edwards (2001) reported medium ground corn (870 µm dgw) resulted in better FCR in broiler than those fed with FC (290 µm dgw). Similarly, Amerah (2008) reported coarse grinding improved FCR of broiler fed both wheat- and corn-based diets than with fine grinding. The FCR improvement was probably related to enhanced gizzard activity caused by dietary inclusion of coarse grain. Enhanced gizzard activity resulted in a longer grinding and retention time to produce the appropriately particle size of digesta, as evidenced by similar particle size distribution in the duodenal digesta between fine and coarse diets (Hetland et al., 2002, 2003; Amerah et al., 2008; Chapter V). Concurrently, GIT motility could be improved by a well-developed gizzard musculature (Ferket, 2000) through increased levels of cholecystokinin release (Svihus et al., 2004), which in turn stimulated the secretion of pancreatic enzymes and GIT refluxes (Duke, 1992). Longer digesta retention time and lower pH in the GIT improves digestive efficiency by increasing enzyme exposure time to degrade substrates and thus improve feed efficiency (Gabriel et al., 2003).

As expected, we observed males to have better growth than females, as reported by other researchers (Hamilton et al., 1995; Ziaer et al., 2007; Lilly et al., 2011; Chewning et al., 2011).

Placing broiler chicks on new litter decreased feed intake and improved AdjFCR during the 0 to 14 d period in comparison to chicks placed on fine old litter. This litter consistency effect could be explained by our visual observations of new litter being present in gizzard contents. Evidently, the young birds consumed some new litter material in addition to the feed in order to satisfy an appetite for dietary structure or fiber. Several reports indicated that dietary insoluble fiber stimulates gizzard function and improves feed efficiency (Duke, 1986; Svihus et al., 2001). Hetland et al. (2005) reported over 50% heavier gizzards in birds reared on litter floors than in cages, which appeared to be a result of the birds consuming the litter materials. The diminishing effect of litter consistency at placement as the birds aged may due to reduced litter consumption after the litter began to cake during later period of the study, which normally occurs under normal broiler management conditions.

The effects of gender and dietary CC inclusion on absolute and relative proventriculus and gizzard weight at 35 and 49 d of age in Experiment 1 are shown in Table 3-6. An interaction between CC inclusion and gender was observed for absolute proventriculus weight at 35 d of age ($P < 0.05$). Dietary inclusion of 50% CC decreased absolute proventriculus weight ($P < 0.01$), but this effect was greater in males than in females ($P < 0.01$). The birds fed the 50% CC diet exhibited smaller proventriculus but larger gizzard weights at 35 and 49 d of age ($P < 0.01$). The relative proventriculus weight at 35 d was not influenced by 50% CC inclusion, but it was decreased at 49 d of age ($P < 0.01$). Relative gizzard weight was increased at 35 and 49 d by 50% CC inclusion ($P < 0.01$). Males had larger proventriculus and gizzard weights at both 35 and 49 d of ages than females ($P < 0.01$), but they had similar relative proventriculus and smaller relative gizzard weights. Increased gizzard weight due to increased corn particle size was a logical consequence of enhanced mechanical grinding activity (Dahlke et al., 2003; Parsons et al., 2006), but the inverse relationship between gizzard and proventriculus weights has seldom been reported in literature. The relative relationship between gizzard and proventriclus weights indicated that broilers may adjust their mechanical and enzymatic digestive function according to the physical structures of feed. We observed the proventriculus was often observed to be swollen in conjunction with a less functioning or atrophied gizzard in birds fed the fine mash diet. Similarly, Gabriel et al. (2003 and 2008) reported fine-wheat-fed birds exhibited a more dilated proventriculus than birds fed whole wheat.

The effects of litter type and dietary CC inclusion on litter moisture, pH, and N content are shown in Table 3-7. No treatment interaction was observed. However, the 50% dietary CC inclusion treatment decreased litter moisture ($P < 0.05$) and litter N ($P < 0.05$), and increased litter pH ($P < 0.05$), whereas litter type had no influence on litter characteristics. Decreased litter N and litter moisture could be explained by reduced N intake, greater N digestibility, or greater N volatilization from litter with CC inclusion. Coufal et al. (2006) reported top-dressing new wood shavings on old litter had no consistent effect on overall litter moisture, but reduced litter N content by increased N volatilization, and litter pH values were significantly greater for top-dressed pens as compared with old litter control pens in this previous study.

The effects of dietary CC inclusion on colon bacterial distribution at the phylum and family levels are shown in Table 3-8. On the phylum level, birds fed 50% CC had a significantly greater percentage of Firmicutes group ($P < 0.05$), but a smaller percentage in the Proteobacteria group ($P < 0.05$) in the colon. On the family level, 50% dietary CC significantly decreased Enterobacteriaceae ($P < 0.05$). Proteobacteria have been defined as a major group of bacteria that include a wide variety of pathogens, such Escherichia, Salmonella, Vibrio, and Helicobacter. Enterobacteriaceae is the only representative in the order Enterobacteriales of the class Gammaproteobacteria in the phylum Proteobacteria that include many familiar pathogens, such as Escherichia, Salmonella, Yersinia pestis, Klebsiella, and Shigella (George, 2005). Jacobs (2011) reported that chicks fed diets containing large ground corn particles, whole sorghum, or whole wheat had a significantly fewer ($P < 0.05$) cecal bifidobacteria and perfringens populations, as well as cecal lactobacilli and E. coli populations ($P < 0.05$) as compared to chicks fed fine ground corn. Molist et al. (2010) reported that dietary wheat bran reduced enterobacteria and E. coli counts in the intestinal digesta and feces of piglets, while Molist et al. (2012) concluded that the dietary inclusion of wheat bran increased the presence of Firmicutes.

Birds fed 0% CC tended to have higher percentage of Vibrionaceae (6.3% *versus* 1.1%, $P = 0.11$), which has been found to be pathogenic to humans, and may cause gastroenteritis that leads to acute and fatel septicemias. Birds fed 0% CC had a numerically higher percentage of

Pasteurellaceae (3.0% *versus* 14.2%), which comprise a large and diverse family of Gram-negative Proteobacteria, with members ranging from important pathogens, such as Haemophilus influenza, to commensals of the animal and human mucosa (Kuhnert, 2008). Although birds consuming 50% CC diets exhibited a numerically higher percentage of Clostridiaceae (0.6% *versus* 16.0%), the differences were not significant because of the high variation among replicates. Although, this effect was surprising, it may be due to the reduced population in the mucosa that led to a greater luminal population.

The acidic GIT environment and greater nutrient digestibility due to enhanced gizzard activity caused by structural material could be the reasons that few pathogens were found in the colon and ileum (Gabriel et al., 2003; Engberg et al., 2004; Jimenez-Moreno et al., 2009; Senkoylu et al., 2009). Larger particle size grains in broiler diets may provide a method to potentially improve GIT health.

In conclusion, dietary inclusion of 50% CC decreased feed intake throughout the 49 d study, but improved AdjFCR as the birds aged. Dietary inclusion of 50% CC increased relative gizzard weight and decreased relative proventriculus weight. Dietary inclusion of 50% CC modulated GIT physiology and ecosystem, as evidenced by lower litter N, increased litter pH, decreased litter moisture, and by completely altering the colon bacterial profile. New litter only decreased feed intake and improved AdjFCR at 14 d of age.

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Table 3-1. Ingredient composition and calculated analysis for broiler dietary treatment of starter, grower, and finisher diet

Item	Starter	Grower	Finisher
Ingredient		(%)	
Corn	59.30	67.16	71.45
Soybean meal, 48% CP	35.80	28.18	23.92
Limestone	0.97	1.02	1.07
Dicalcium phosphate, 18% P	2.09	1.85	1.57
DL-Methionine	0.19	0.13	0.10
L-Lysine	----	0.06	0.21
L-Threonine	0.05	----	0.08
Sodium chloride	0.50	0.50	0.50
Vitamin premix[1]	0.05	0.05	0.05
Choline chloride, 60%	0.20	0.20	0.20
Trace mineral premix[2]	0.20	0.20	0.20
Selenium premix[3]	0.10	0.10	0.10
Coccidiostat[4]	0.05	0.05	0.05
Poultry fat	0.50	0.50	0.50
Total	100.00	100.00	100.00
Calculated analysis			
ME, kcal/g	2.94	3.02	3.07
Protein, %	23.00	20.00	18.50
Calcium, %	0.90	0.85	0.80
Available phosphorus, %	0.45	0.40	0.35
Total lysine, %	1.26	1.10	1.10
Total methionine + cysteine, %	0.95	0.83	0.75

[1] The vitamin premix supplied the following per kg of feed: vitamin A, 6601; cholecalciferol, 1980 IU; niacin, 55 mg; α-tocopheral, 33 mg; pantothenic acid 11 mg; riboflavin, 6.6 mg; pyridoxine, 4 mg; menadione, 2 mg; thiamin, 2 mg; folic acid, 1.1 mg; biotin, 0.13 mg; and vitamin B12, 0.02 mg.

[2] The mineral premix supplied the following per kg of feed: Zn, 120 mg; Mn, 120 mg; Fe, 80 mg; Cu, 10 mg; I, 2.5 mg; Co, 1.0 mg.

[3] Selenium premix provided 0.2 ppm Se.

[4] Monensin was included at 99 mg/kg (Coban 90, Elanco Animal Health, Indianapolis IN, USA).

Table 3-2. Effect of gender and dietary coarse corn (CC) on feed intake and BW gain from 0 to 49 d of age in Experiment 1

CC	Gender	n	Feed Intake				BW gain			
			0-14 d	15-35 d	36-49 d	0-49 d	0-14 d	15-35 d	36-49 d	0-49 d
Interaction Effects[1]							(g/bird)			
0%	Female	18	563	2523^{C}	2916	6002	395	1490^{C}	1303	3188
0%	Male	18	608	3001^{A}	3540	7149	418	1817^{A}	1702	3937
50%	Female	18	508	2482^{C}	2865	5855	348	1444^{C}	1310	3102
50%	Male	18	521	2816^{B}	3466	6803	354	1708^{B}	1772	3834
SEM			7.7	20.0	24.0	40.3	4.8	13.8	11.5	22.0
Main Effects										
0%		36	586^{A}	2762^{A}	3228	6576^{A}	407^{A}	1654^{A}	1502	3563^{A}
50%		36	514^{B}	2649^{B}	3166	6329^{B}	351^{B}	1576^{B}	1541	3468^{B}
SEM			5.4	14.1	16.9	28.5	3.4	9.7	11.5	15.6
	Female	36	536^{B}	2502^{B}	2891^{B}	5929^{B}	371^{B}	1467^{B}	1307^{B}	3105^{B}
	Male	36	564^{A}	2908^{A}	3503^{A}	6975^{A}	386^{A}	1763^{A}	1737^{A}	3886^{A}
	SEM		5.4	14.1	16.9	28.5	3.4	9.7	11.5	15.6
Source of variation							*P-value*			
CC × Gender			0.06	< 0.01	0.76	0.11	0.10	0.03	0.21	0.69
CC			< 0.01	< 0.01	0.09	< 0.01	< 0.01	< 0.01	0.13	< 0.01
Gender			< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

[a-b] Means within a column with different superscripts differ significantly ($P < 0.05$).

[A-C] Means within a column with different superscripts differ significantly ($P < 0.01$).

[1] Treatments consisted of female or male and 0 or 50% CC inclusion rate.

Table 3-3. Effect of gender and dietary coarse corn (CC) on adjusted feed conversion ratio (AdjFCR) and total mortality of broilers from 0 to 49 d of age in Experiment 1

CC	Gender	n	AdjFCR[2]				Mortality
			0-14 d	15-35 d	36-49 d	0-49 d	0-49 d
Interaction Effects[1]			(g of feed/g of BW gain)				%
0%	Female	18	1.34	1.69	2.24	1.88	0.69
0%	Male	18	1.37	1.64	2.16	1.82	6.25
50%	Female	18	1.37	1.72	2.22	1.89	2.78
50%	Male	18	1.37	1.64	2.01	1.77	3.47
SEM			0.01	0.01	0.31	0.01	0.98
Main Effects							
0%		36	1.36	1.67	2.20^{a}	1.85	3.47
50%		36	1.37	1.68	2.11^{b}	1.82	3.13
SEM			0.01	0.01	0.22	0.01	0.69
	Female	36	1.36	1.71^{A}	2.23^{A}	1.91^{A}	1.74^{b}
	Male	36	1.37	1.64^{B}	2.08^{B}	1.79^{B}	4.86^{a}
	SEM		0.01	0.01	0.22	0.01	0.69
Source of variation			*P-value*				
CC × Gender			0.61	0.46	0.16	0.22	0.11
CC			0.45	0.39	< 0.05	0.71	0.84
Gender			0.31	< 0.01	< 0.01	< 0.01	0.04

$^{a\text{-}b}$ Means within a column with different superscripts differ significantly ($P < 0.05$).

$^{A\text{-}C}$ Means within a column with different superscripts differ significantly ($P < 0.01$).

[1] Treatments consisted of female or male and 0 or 50% CC inclusion rate.

[2] AdjFCR=Feed intake per pen/total BW gain, including BW of mortality that occurred during the time period.

Table 3-4. Effect of litter type and dietary coarse corn (CC) on feed intake and BW gain, adjusted feed conversion ratio (AdjFCR), and total mortality of broilers from 0 to 49 d of age in Experiment 2

CC	Litter	n	Feed Intake					BW gain				
			0-14 d	15-28 d	29-42 d	43-49 d	0-49 d	0-14 d	15-28 d	29-42 d	43-49 d	0-49 d
Interaction Effects[1]							(g/bird)					
0%	Old	8	590	1811	3104	1506	7011	407	1100	1564	582	3653
0%	New	8	556	1755	3058	1437	6806	401	1060	1583	545	3589
50%	Old	8	511	1712	3027	1420	6670	359	1048	1591	565	3563
50%	New	8	494	1716	3029	1414	6653	364	1042	1614	580	3600
SEM			9.5	22.0	34.2	23.5	71.9	2.8	10.8	13.0	20.5	30.0
Main Effects												
0%		16	573^{A}	1783^{A}	3081	1471^{a}	6908^{A}	404^{A}	1080^{A}	1573^{b}	563	3620
50%		16	502^{B}	1714^{B}	3028	1417^{b}	6661^{B}	362^{B}	1045^{B}	1603^{a}	573	3583
SEM			6.7	15.5	24.2	16.6	50.9	4.2	7.6	9.2	14.5	20.1
	Old	16	550^{a}	1761	3066	1463	6840	383	1074	1578	573	3608
	New	16	525^{b}	1735	3043	1425	6728	383	1051	1598	563	3595
	SEM		6.7	15.5	24.2	16.6	50.9	4.2	7.6	9.2	14.5	20.1
Source of variation							*P-value*					
CC * Litter			0.38	0.19	0.48	0.19	0.19	0.33	0.12	0.87	0.21	0.09
CC			< 0.01	< 0.01	0.14	0.03	< 0.01	< 0.01	< 0.01	0.03	0.66	0.20
Litter			0.01	0.25	0.52	0.12	0.14	0.33	0.14	0.12	0.62	0.65

[a-b] Means within a column with different superscripts differ significantly ($P < 0.05$).

[A-B] Means within a column with different superscripts differ significantly ($P < 0.01$).

[1] Treatments consisted of old litter or new litter and 0 or 50% CC inclusion rate.

Table 3-5. Effect of litter type and dietary coarse corn (CC) on adjusted feed conversion ratio (AdjFCR) and total mortality of broilers from 0 to 49 d of age in Experiment 2

CC	Litter	n	AdjFCR (g:g)[2]					Mortality
			0-14 d	15-28 d	29-42 d	43-49 d	0-49 d	49 d
Interaction Effects[1]			(g of feed/g of BW gain)					%
0%	Old	8	1.46	1.65	2.01	2.70	1.92	7.03
0%	New	8	1.40	1.66	1.94	2.73	1.90	4.69
50%	Old	8	1.41	1.64	1.90	2.56	1.87	3.13
50%	New	8	1.36	1.66	1.90	2.48	1.85	3.91
SEM			0.02	0.02	0.02	0.06	0.02	1.30
Main Effects								
0%		16	1.43	1.65	1.97^{A}	2.71^{A}	1.91^{A}	5.86
50%		16	1.39	1.65	1.90^{B}	2.52^{B}	1.86^{B}	3.52
SEM			0.02	0.01	0.01	0.04	0.01	0.92
	Old	16	1.43^{a}	1.65	1.96	2.63	1.90	5.08
	New	16	1.38^{b}	1.66	1.92	2.60	1.87	4.30
	SEM		0.02	0.01	0.01	0.04	0.01	0.92
Source of variation			*P-value*					
CC * Litter			0.87	0.06	0.24	0.36	0.59	0.70
CC			0.09	< 0.01	< 0.01	< 0.01	< 0.01	0.11
Litter			0.02	0.12	0.12	0.65	0.12	0.13

[a-b] Means within a column with different superscripts differ significantly ($P < 0.05$).

[A-B] Means within a column with different superscripts differ significantly ($P < 0.01$).

[1] Treatments consisted of old litter or new litter and 0 or 50% CC inclusion rate.

[2] AdjFCR=Feed intake per pen/total BW gain, including BW of mortality that occurred during the time period.

Table 3-6. Effect of gender and dietary coarse corn (CC) on absolute and relative gizzard and proventriculus weight at 35 and 49 d of age in Experiment 1

			35 d					49 d				
CC	Gender	n	BW	Proventriculus		Gizzard		BW	Proventriculus		Gizzard	
Interaction Effects[1]			(kg)	(g)	(mg:g)	(g)	(mg:g)	(kg)	(g)	(mg:g)	(g)	(mg:g)
0%	Female	8	4.2^{c}	5.9^{c}	1.4	23.4	5.6	7.1	7.1^{c}	1.0	32.9	4.6
0%	Male	8	5.1^{a}	7.6^{a}	1.5	25.6	5.0	8.7	9.1^{a}	1.0	35.3	4.0
50%	Female	8	4.1^{c}	5.7^{c}	1.4	26.9	6.7	6.9	6.6^{d}	0.9	35.7	5.2
50%	Male	8	4.7^{b}	6.8^{b}	1.4	30.0	6.4	8.5	8.1^{b}	0.9	40.8	4.8
SEM			0.4	0.1	0.1	0.5	0.1	0.1	0.1	0.2	0.8	0.1
Main Effects												
0%		16	4.7^{A}	6.7^{A}	1.4	24.5^{B}	5.3^{B}	7.9^{a}	8.1^{A}	1.03^{A}	34.1^{B}	4.3^{B}
50%		16	4.4^{B}	6.3^{B}	1.4	28.5^{A}	6.5^{A}	7.7^{b}	7.4^{B}	0.96^{B}	38.3^{A}	5.0^{A}
SEM			0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.01	0.6	0.1
	Female	16	4.1^{B}	5.8^{B}	1.4	25.2^{B}	6.1^{A}	7.0^{B}	6.9^{B}	0.10	34.3^{B}	4.9^{A}
	Male	16	4.9^{A}	7.2^{A}	1.5	27.8^{A}	5.7^{B}	8.6^{A}	8.6^{A}	0.10	38.1^{A}	4.4^{B}
	SEM		0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.01	0.6	0.1
Source of variation							*P-value*					
CC * Gender			0.01	0.02	0.39	0.32	0.21	0.71	0.07	0.30	0.09	0.12
Coarse Corn			< 0.01	< 0.01	0.66	< 0.01	< 0.01	0.02	< 0.01	< 0.01	< 0.01	< 0.01
Gender			< 0.01	< 0.01	0.09	< 0.01	< 0.01	< 0.01	< 0.01	0.22	< 0.01	< 0.01

$^{a-c}$ Means within a column with different superscripts differ significantly ($P < 0.05$).

$^{A-B}$ Means within a column with different superscripts differ significantly ($P < 0.01$).

[1] Treatments consisted of female or male and 0 or 50% CC inclusion.

[2] RWPro=Relative weight of proventriculus=Proventriculus:BW (mg:g); RWGizd=Relative weight of gizzard=Gizzard:BW (mg:g)

Table 3-7. Effect of litter type and dietary coarse corn (CC) on litter moisture, pH, and nitrogen content at 49 d of age in Experiment 2

CC	Litter	n	Moisture	pH	Nitrogen
Interaction Effects[1]			(%)		(%)
0%	Old	8	40.62	7.99	3.05
0%	New	8	39.37	8.27	3.04
50%	Old	8	36.11	8.69	2.90
50%	New	8	35.71	8.66	2.73
SEM			1.91	0.15	0.07
Main Effects					
0%		16	40.00^{a}	8.13^{b}	3.05^{a}
50%		16	35.91^{b}	8.68^{a}	2.81^{b}
SEM			1.35	0.10	0.05
	Old	16	38.37	8.34	2.97
	New	16	37.54	8.47	2.89
	SEM		1.35	0.10	0.05
Source of variation				*P-value*	
Coarse Corn * Litter			0.82	0.31	0.30
Coarse Corn			< 0.05	< 0.01	< 0.01
Litter Form			0.67	0.41	0.25

$^{a-b}$ Means within a column for n pens with different superscripts differ significantly ($P < 0.05$).
$^{A-B}$ Means within a column for n pens with different superscripts differ significantly ($P < 0.01$).
[1] Treatments consisted of old litter or new wood shavings litter and 0 or 50% CC inclusion.

Table 3-8. Effect of dietary coarse corn (CC) on colon bacterial distribution at phylum and family level in Experiment 1

	0% CC		50% CC	*P*-value
Phylum Level		%		
Bacteroidetes	7.0		9.3	0.64
Chlorobi	0.0		16.2	0.32
Firmicutes	1.8^b		22.8^a	< 0.05
Proteobacteria	75.2^a		9.4^b	< 0.05
Tenericutes	1.5		18.2	0.34
ND	13.9		21.4	0.33
Other known species	0.6		2.7	
	100.0		100.0	
Family Level				
Aeromonadaceae	0.1		1.0	0.60
Alcaligenaceae	1.7		0.9	0.57
Alteromonadaceae	0.6		0.1	0.29
Bacteroidaceae	2.2		1.8	0.95
Chlorobiaceae	0.0		16.4	0.26
Clostridiaceae	0.6		16.0	0.23
Comamonadaceae	0.6		1.7	0.75
Cytophagaceae	1.3		3.2	0.65
Enterobacteriaceae	46.4^a		0.3^b	< 0.05
Flavobacteriaceae	2.5		0.6	0.52
Mycoplasmataceae	1.5		11.8	0.51
Nitrosomonadaceae	0.9		0.1	0.28
Pasteurellaceae	14.2		3.0	0.41
Sphingobacteriaceae	1.1		3.3	0.30
Vibrionaceae	6.3		1.1	0.11
ND	13.9		21.4	0.33
Other known species	6.3		17.3	
	100.0		100.0	

[a-b] Means within a row with different superscripts differ significantly ($P < 0.05$) by 2 tailed T-Test.

ND= Not determined

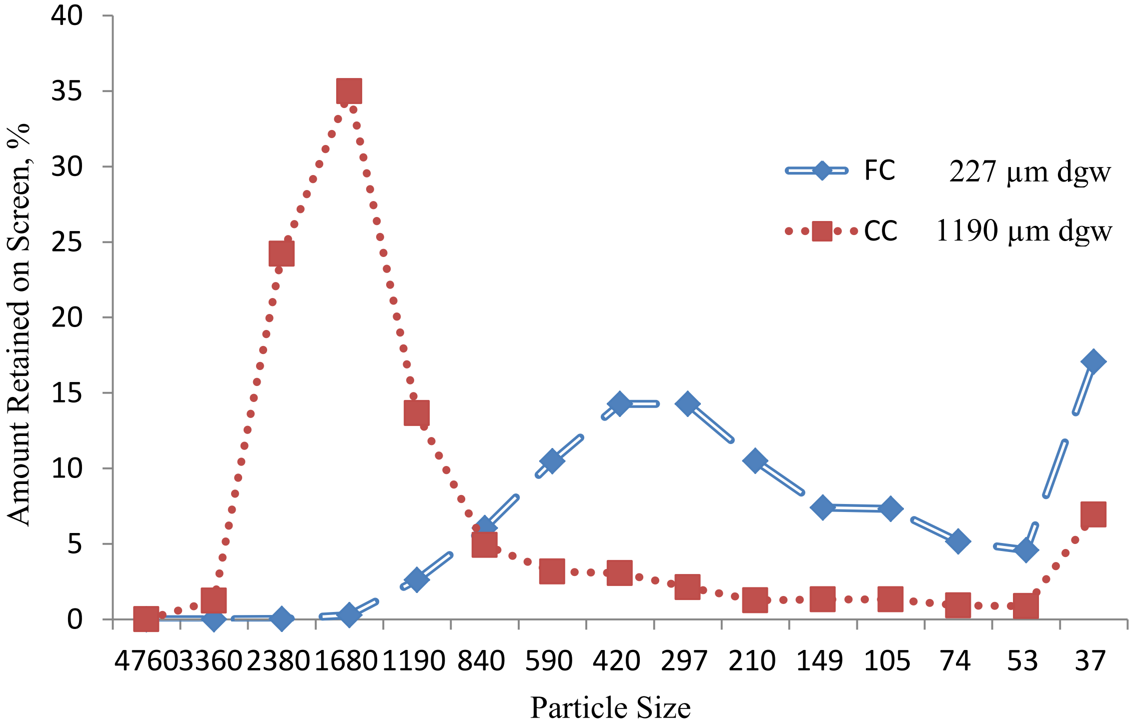

Figure 3-1. The geometric mean diameter by mass (dgw) and particle size distribution of fine corn (FC) and coarse corn (CC)

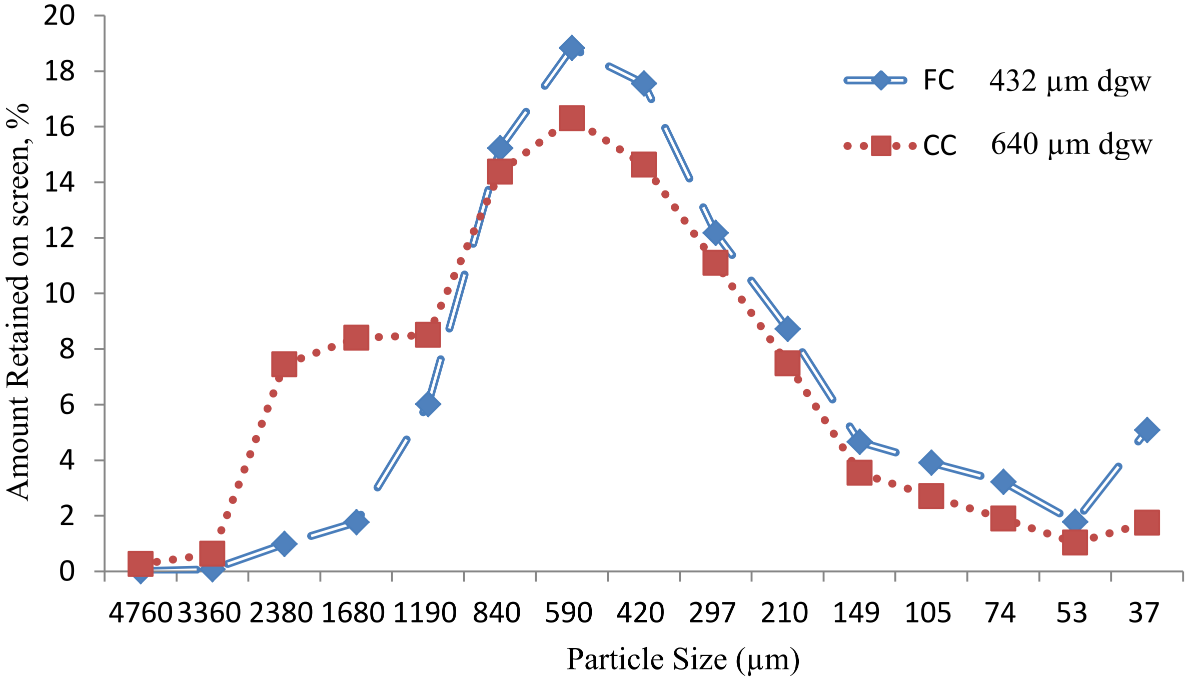

Figure 3-2. The geometric mean diameter by mass (dgw) and particle size distribution of mash diets prior to pelleting with 0 and 50% CC replaced FC

CHAPTER 4

Effects of Dietary Coarsely Ground Corn and Litter Type on Broiler Live Performance, Litter Characteristics, Gastrointestinal Tract Development, Apparent Ileal Digestibility of Energy and Nitrogen, and Intestinal Morphology

ABSTRACT

The objectives of this study were to evaluate the effects of the dietary inclusion of two coarsely ground corn levels (0 or 50% CC) of broilers reared on two litter types (finely ground old litter or new wood shavings litter) on live performance, litter characteristics, gastrointestinal tract (GIT) development, apparent ileal digestibility (AID) of energy and nitrogen (N), and intestinal morphology. No CC level × litter type interaction effects were observed on live performance. Dietary inclusion of 50% CC increased BW at 35 d ($P < 0.01$) and improved cumulative AdjFCR at 35 and 49 d of age ($P < 0.01$). No litter effect was observed on live performance. The 50% CC treatment increased absolute and relative gizzard weight ($P < 0.01$) and decreased jejunum unit weight (g/cm) ($P < 0.01$). New litter increased absolute and relative proventriculus weight ($P < 0.01$). A CC level × litter type interaction effect was observed for litter, where the 50% CC treatment reduced litter N regardless of litter type ($P < 0.01$), but litter N was only reduced by new litter among those fed 0% CC ($P < 0.05$). The 50% CC inclusion increased litter pH and improved the AID of energy and N by 6.8% ($P < 0.01$) and 3.5% ($P < 0.05$), respectively. The 50% CC treatment increased jejunum villi tip width and villi surface area ($P < 0.05$), and decreased the muscularis layer thickness ($P < 0.01$), whereas new litter increased jejunum villi and ileum villi height ($P < 0.05$), jejunum villi surface area ($P < 0.01$), and jejunum villi height: crypt depth ratio ($P < 0.01$). The results of this study indicated that birds fed pelleted and screened diets containing 50% CC had improved AdjFCR and AID of energy and N, in response to enhanced GIT functional development and intestinal mucosa morphology.

INTRODUCTION

The physical structure of feed may enhance digestive capacity, and thereby improve broiler live performance, and feed nutrient utilization efficiency. Growth performance efficiency has been influenced by several factors associated with textural properties of feed, including feed form (Chewning et al., 2012), crumble quality (Hu et al., 2012), pellet length and size (Cerrate et al., 2009; Abdollahi et al., 2013), pellet hardness (Parsons et al., 2006), pellet durability index (PDI) (Cutlip et al., 2008), percentage fines (Lilly et al., 2011; Corzo et al., 2011), particle size (Nir et al., 1994), feed texture (Hamilton et al., 1995), dietary fiber (Gonzales-Alvarado et al., 2007), and coarsely ground grain (Dozier et al., 2006; Xu et al., 2013). In deeded, broilers may have a requirement for physical structure in feed to satisfy their innate feeding behavior and/or gastrointestinal tract (GIT) development, or digestive function needs.

Dietary structural components, such as whole wheat, coarsely ground grain, or dietary fiber, may improve broiler feed and growth efficiency through GIT development and function, such as enhanced gizzard activity (Svihus, 2002), extended GIT retention time (Hetland et al., 2003; 2005; Gabriel et al., 2008), decreased digesta pH (Gabriel et al., 2003), and altered hind gut bacterial profile (Engberg et al., 2004). Dietary structure was also found to modify intestinal morphology and functionality, such as intestine length (Nir et al., 1994; Amerah et al., 2007), duodenum and jejunum weight, villus height, and crypt depth (Dahlke et al., 2003; Sarikhan et al. 2010). In our previous studies, dietary inclusion of 50% coarse corn (CC) was observed to decrease feed grinding cost and improve broiler live performance, while litter texture had a marginal effect on broiler live performance (Chapter 3). A better understanding of how improving GIT digestive function by dietary inclusion of CC is necessary to optimize feed manufacturing strategies and improve broiler live performance.

The objectives of this study were to evaluate the effects of dietary CC inclusion and floor litter type on broiler live performance, litter characteristics, GIT development, AID of energy and N, and intestinal morphology.

MATERIALS AND METHODS

Feed Formulation, Manufacture, and Experiment Design

Corn-soy broiler diets (Table 4-1) were formulated and manufactured at the North Carolina State University Feed Mill Education Unit to meet or exceed the NRC suggested minimum requirements of broilers (NRC, 1994). The two CC treatment diets were produced by replacing 0 or 50% of the total corn as CC in a basal diet that contained fine corn (FC). The FC and soybean meal were ground with a hammermill (Model 1522, Roskamp Champion, Waterloo, IA) equipped with two 2.4 mm screens, while the CC was ground with a two-pair roller mill (Model C128829, RMS, Tea, SD) with a gap setting of 0% opening on top and 100% opening on bottom. Dry ingredients were blended in a double ribbon mixer (TRDB126-0604, Hayes & Stolz Ind. Mfg. Co., Fort Worth, TX) to produce the mash diets. The mash diets were steam conditioned to 85°C for 20 seconds and pelleted with a pellet mill (Model PM1112-2, California Pellet Mill Co., Crawfordsville, IN) equipped with a ring die (4.4 mm by 35 mm). Pellets were cooled with ambient air in a counter-flow cooler (Model Vk09 × 09KL, Geelen Counterflow Inc., Orlando, Florida). A single starter feed with 0% CC was provided to all birds as crumbles from 1 to 14 d, and subsequently the two CC inclusion (0 or 50%) treatments in grower and finisher feeds were fed as pellets with fines removed with a pellet screener (Model 35/7 Roto-Shaker, Sprout Bauer Inc., Muncy, PA). Particle size distribution was determined by ASAE S319.3 and the pellet durability index was determined by ASAE standard S269.4.

Husbandry Practices

This experiment was conducted at the North Carolina State University Chicken Educational Unit. The care of the birds in the study conformed to the Guide for Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010). A total 1,024 Ross 344 × 708 (Aviagen, Huntsville, AL) 1-d-old male broiler chicks were feather sexed, weighed, and placed in a curtain-sided, heated, and fan-ventilated broiler house until 49 d of age. On the day of hatch, 32 chicks were assigned per pen with 32 pens in total. Care was taken to distribute incubator tray position effects uniformly among all of the broiler pens. Each side of 16 pens was considered a block. Each pen was 1.2 m width by 3.8 m length. The stocking density was 7 chicks/m^2. Each pen contained one bell-type drinker and two tube feeders. Each pen was assigned to one of four factorial treatments (finely ground old litter or new wood shavings litter and 0 or 50% CC) with 6 replicates per interaction. The chicks were given a budget of 0.9, 2.7, and 3.6 kg of starter, grower, and finisher diets, respectively. The birds had *ad libitum* access to water and feed throughout the study.

Feeders were shaken once per day from 1 to 14 d and twice per day from 15 to 49 d to minimize variation in feed intake due to feed flow characteristics. The lighting program was

23 h of light from 1 to 7 d, 22 h of light to 14 d, 20 h of light to 21 d, and natural light from 22 to 49 d of age. The temperature of the house from placement to 7 d was maintained approximately at 32 to 34°C, 29°C to 14 d, 27 °C to 21 d, and ambient thereafter.

Data Collection

Initial pen BW was collected at placement. Feed intake and BW by pen were recorded at 14, 35, and 49 d of age. Birds were observed daily and mortalities were removed and weighed to calculate adjusted feed conversion ratio (AdjFCR). At 45 d of age, litter samples were taken from six evenly distributed positions within each pen, and mixed to create a composite sample for each pen. The moisture, pH, and N content were determined for each sample. Moisture was determined by loss on drying at 100°C (Method 934.01, AOAC, 2006a), and the pH of the gizzard and proventriculus digesta was measured with a portable pH meter (HACH IQ150 pH/mV/Temperature System) at the time of necropsy. Litter N content was determined by Nitrogen Combustion Analysis (Method 990.03, AOAC, 2006b). At 49 d of age, 3 birds per pen close to the average BW were selected and individually weighed, killed and the gizzard was excised. The fat surrounding the gizzard was trimmed, contents removed, rinsed, blotted dry, and weighed. The data was expressed as a percentage of BW (mg/g BW).

Celite^{TM} was added to the finisher diet as an indigestible marker to determine apparent ileal digestibility (AID) of energy and nitrogen (N). At 50 d of age, 3 birds of average BW within each pen were necropsied to collect ileal content. Ileal content was analyzed for moisture (Method 934.01, AOAC, 2006a), crude protein (Method 990.03, AOAC, 2006b), acid insoluble ash (Vogtmann et al., 1975), and gross energy (Merrill and Watt, 1973). Gross energy was determined with an adiabatic bomb calorimeter (Model C5003, IKA, Wilmington, NC). Apparent ileal digestibility of energy and N were calculated using the following equation:

$$AID = 100\% - [(ID \times AF) / (AD \times IF)] * 100\%$$

Where:

AID = Apparent ileal digestibility (%)

ID = Marker concentration in diet (%)

AF = Energy or N concentration in ileal digesta (%)

AD = Energy or N concentration in diet (%)

IF = Marker concentration in ileal digesta (%)

Histological sampling and analysis were conducted with the following procedure. At 50 d of age, one bird per pen approximating the average BW of the pen was selected. After the abdominal incision, the intestines were located and a middle (5 cm) section of the jejunum and ileum were collected. The content of each GIT section was gently flushed with a saline solution (NaCl, 0.9%). Each intestinal section sample was fixed in a vial with 10% formalin solution. After a period of not less than 48 h, each of these fixed samples was removed from the formalin solution, and a middle section was dissected (0.5 cm) and stored in an individual histology cassette with proper identification, rinsed in distilled water, and immediately placed in a container with 70% ethanol. All the cassettes (sections) were processed at NCSU Veterinary Medicine Pathology laboratory. Samples were stained with Alcian Blue (pH 2.5) following a standard procedure to make histological slides by the paraffin inclusion method (Weesner, 1960).

Three cross-sections were obtained from each intestinal section sample for further staining and evaluation. The slides were examined using an optical microscope (Micromaster, Fisher Scientific, CAT. No. 12-562-27) fitted with a digital camera and the images were analyzed using image analysis software (UTHSCSA Image Tool, version 3.00). Two images of each section were captured from each sample with a final magnification of 4 × and the following variables were measured: the thickness of the muscular, villus height, villus tip and base width, and crypt depth. The surface areas of the villus and crypt were calculated as the product of the height multiplied by the width. An average value was calculated for each GIT segment from each bird. The villus height:crypt depth ratio was then calculated.

Statistical Analysis

This experiment was analyzed as a 2 × 2 factorial arrangement in a randomized complete block design to determine main and interaction effects, with 2 litter types (finely ground old litter or new wood shavings litter) and 2 dietary inclusions of CC (0 or 50%). A pen of birds served as the experimental unit for the statistical analysis of the live performance data. All data were analyzed using PROC GLM of SAS (Version 9.1, SAS Institute Inc., Cary, NC). Differences were considered significant at $P < 0.05$ or $P < 0.01$, and the differences between means were separated by least significant difference.

RESULTS AND DISCUSSION

The geometric mean diameter by mass (dgw) and particle size distribution of FC, CC, and mash diets prior pelleting with 0 or 50% CC replaced FC are shown in Figures 4-1 and 4-2. The geometric mean diameter (dgw) of FC, CC, SBM, and DDGS was 294, 1359, 347, and 414 µm, respectively.

As 50% CC replaced FC in the diets, the dgw of the grower diet in mash form increased from 415 to 630 µm, and from 389 to 651 µm for finisher diet in mash form. The hammermill and roller mill are two commonly used grinding methods to reduce the particle size of the grains. Hammermill grinding produces a wider particle size distribution than roller mill grinding (Nir et al., 1995). By mixing the corn ground by these two methods, we produced a biphasic particle size, with the larger particles intended to stimulate gizzard function and the smaller particles intended to improve pellet quality and nutrient utilization. Pellet quality, as determined by the Pellet Durability Index (PDI), was decreased from 93.5 to 91.3% in the grower diet and from 93.0% to 92.6% in the finisher diet, as 50% CC was included. The screened percentage fines of the grower diet was 13% in 0% CC diet and 18% in 50% CC diet, as well as 12% and 19% in the finisher diet, respectively.

The effects of dietary CC inclusion and litter type on feed intake, BW, and AjdFCR from 0 to 49 d of age are shown in Table 4-2. No diet × litter type interaction effects were observed. The pelleted and screened diets that contained 50% CC did not affect FI, but birds fed these diets had increased BW at 35 d ($P < 0.01$) and improved cumulative AdjFCR at 35 d and 49 d age ($P < 0.01$). Lott et al. (1992) and Amerah et al. (2008) reported that dietary inclusion of CC decreased feed intake and BW, which was thought to be related to the young bird's limited ability to utilize coarse particle and poorer quality pellets (Corzo et al., 2011; Lilly, 2011). As compared with a similar management scenario in our previous study, in which 50% CC decreased feed intake and BW at 14, 28, and 35 d ($P < 0.01$), we concluded that broilers may not be able to fully utilize 50% CC at an early age. Moreover, reduced pellet quality caused by CC inclusion was another confounding factor that adversely affected feed intake. But in present study, birds fed screened whole pellet grower and feed finisher diets with 50% CC exhibited the same feed intake with improved AdjFCR. Hu et al. (2012) reported that birds fed 100% pellets had greater feed intake and BW than birds fed 50% pellets. Mckinney et al. (2004) estimated that the process of pelleting contributed 187 kcal of effective energy per kg of diet at 100% pellet, which declined in a curvilinear manner as percentage pellets of the feed decreased. It was also observed that as the proportion of pellets in the feeder increased, birds ate less frequently and rested more frequently. Apparently, less metabolic energy was expended by activity associated with feeding behavior.

The effects of dietary CC inclusion and litter type, and their interaction on GIT development are shown in Table 4-3. No diet × litter type interaction effects were observed. At 49 d of age, dietary inclusion of 50% CC significantly increased absolute and relative gizzard weight ($P < 0.01$) and the gizzard:proventriculus ratio ($P < 0.05$), but it decreased jejunum unit weight ($P < 0.01$). New litter only increased proventriculus weight ($P < 0.05$). Neither dietary CC inclusion nor litter type influenced tensile strength of the jejunum and ileum. Dahlke et al. (2003) and Parsons et al. (2006) reported that gizzard weight increased linearly as corn particle size increased, which is a logical consequence of physical stimulation of gizzard grinding activity. The gizzard:proventriculus ratio could reflect the mechanical digestion and functional enzymatic digestion balance in the unique gastric organs of poultry. Our previous studies suggested that broilers may have the ability to adjust their digestive function according to diet structure and nutrient composition. Dietary inclusion of 50% CC decreased jejunum unit weight ($P < 0.01$), but this was not consistent with other experiments. Dahlke et al. (2003) reported corn particle size produced a quadratic effect on duodenum, jejunum, and ileum weights, but Nir et al. (1995) found no differences in the intestine segment weight as corn particle size increased from 0.6 to 2.17 mm. Amerah et al. (2007) observed a decrease in the relative length of all components of the digestive tract as grain particle size increased. Decreased intestine weight or length may contribute to improved feed efficiency due to reduced maintenance cost. Tensile strength was not influenced by either dietary CC inclusion or litter type. Dozier et al. (2006) reported that intestinal strength was not affected by dietary inclusion level of CC (15, 25, and 35% CC). Dietary inclusion of CC has been demonstrated to enhance reverse peristalsis (Sacranie, 2006), and was hypothesized to increased intestinal strength due to enhanced muscular activity associated with reverse peristalsis (Savage et al., 1995). The fact that no difference of tensile strength was found in our current study suggested that a fully developed GIT had already been achieved by 49 d of age. However, differences may have been apparent at an earlier age when sampling did not occur.

The effects of dietary CC inclusion and litter type, and their interaction on litter N, moisture, and pH are shown in Table 4-4. No diet × litter type interaction effects were observed. Dietary inclusion of 50% CC decreased litter N by 8.47% ($P < 0.01$) and increased litter pH ($P < 0.05$). No litter type effects were found in this study. As birds exhibited the same feed intake, the reduced litter N indicated improved N utilization, which was consistent with our previous studies. Parsons et al. (2006) reported dietary CC inclusion improved the efficiency of N and lysine retention by broiler.

The effects of dietary CC inclusion and litter type, and their interaction on apparent ileal digestibility (AID) of energy and N are shown in Table 4-5. The AID of energy and N were improved ($P < 0.01$ and $P < 0.05$, respectively) when birds were fed the 50% CC diets. Our previous cage study indicated a tendency towards decreased fecal N as the percentage of dietary CC inclusion increased to 50% at 14 d of age, which also suggested improved N digestibility. A number of studies have shown improved nutrient utilization when birds were fed structural material in their diet (Preston et al., 2000; Svihus and Hetland, 2001; Rougiere et al., 2009). The improved digestibility of nutrients may have arisen from the influence of CC inclusion on decreased digesta pH, greater GIT retention time, or altered intestinal morphology.

The effect of dietary CC inclusion and litter type, and their interaction on intestinal morphology are shown in Tables 4-6, 4-7, and Figure 4-3. There were diet × litter interaction effects on jejunum villi tip width ($P < 0.05$), villi height ($P < 0.01$), and surface area ($P < 0.01$). The 50% CC inclusion treatment increased jejunum tip width and villi surface area (P

< 0.05), and decreased muscularis width (*P* < 0.01). In contrast, new litter increased jejunum and ileum villi height (*P* < 0.05), jejunum villi surface area (*P* < 0.01), and jejunum villi height:crypt depth ratio (*P* < 0.01). There are limited reports on the influence of dietary inclusion of coarsely ground grain on broiler intestine morphology, and the results are inconsistent. Gabriel et al. (2008) reported that whole wheat increased duodenum villus height, crypt depth, and surface area at 23 d. Nir et al. (1994, 1995) reported duodenum villus height increased linearly as dietary particle size increased. However, Amerah et al. (2007) reported that villus height, crypt depth, and epithelial thickness in the duodenum were unaffected (*P* > 0.05) by corn particle size. Dahlke et al. (2003) reported that pelleted diets promoted an increased number of duodenum villi as compared to mash diets, but there was no influence of the corn particle size on this variable. Liu et al. (2006) reported dietary CC inclusion decreased the number of mast cells in the deodenum, jejunum and ileum as compared to finely ground corn diets. With respect to fiber, Sarikhan et al. (2010) and Rezaei et al. (2011) observed that the inclusion of 2.5 to 7.5 g/kg diet of an insoluble fiber (mostly cellulose) with a mean particle size of less than 250 μm increased villus height: crypt depth ratio in the ileum of 42-d-old broilers. The influence of dietary structural material on intestinal morphology may be due to greater digesta retention time, which enhances nutrient availability and facilitates greater contact between nutrient and intestinal villi.

In a conclusion, birds fed pelleted and screened diets that contained 50% CC exhibited improved feed efficiency and AID of energy and N, which may have been due to modified

GIT function, as evidenced by enhanced gizzard development and altered morphological development of the intestinal mucosa.

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Table 4-1. Ingredient composition and calculated analysis for broiler dietary treatment of starter, grower, and finisher diets

Item	Starter	Grower	Finisher
Ingredient		(%)	
Corn	53.65	56.34	63.91
Soybean meal, 48% CP	37.03	27.87	19.82
Dried distillers grains with solubles	5.00	10.00	10.00
Limestone	0.93	1.04	0.95
Dicalcium phosphate, 18% P	1.62	1.57	1.38
DL-Methionine	0.19	0.13	0.10
L-Lysine	0.04	0.13	0.21
L-Threonine	----	----	0.02
Sodium chloride	0.44	0.42	0.43
Vitamin premix[1]	0.05	0.05	0.05
Choline chloride (60%)	0.20	0.20	0.20
Trace mineral premix[2]	0.20	0.20	0.20
Selenium premix[3]	0.10	0.10	0.10
Coccidiostat[4]	0.05	0.05	0.05
Poultry fat	0.50	1.90	2.58
Total	100.00	100.00	100.00
Calculated analysis			
ME, kcal/g	2.95	3.05	3.15
Protein, %	23.18	20.30	17.00
Calcium, %	0.90	0.90	0.80
Available phosphorus, %	0.45	0.45	0.40
Total lysine, %	1.30	1.14	0.97
Total methionine + cysteine, %	0.95	0.83	0.71

[1] The vitamin premix supplied the following per kg feed: vitamin A, 6601; cholecalciferol, 1980 IU; niacin, 55 mg; α-tocopheral, 33 mg; pantothenic acid 11 mg; riboflavin, 6.6 mg; pyridoxine, 4 mg; menadione, 2 mg; thiamin, 2 mg; folic acid, 1.1 mg; biotin, 0.13 mg; and vitamin B12, 0.02 mg.

[2] The mineral premix supplied the following per kg of feed: Zn, 120 mg; Mn, 120 mg; Fe, 80 mg; Cu, 10 mg; I, 2.5 mg; Co, 1.0 mg.

[3] Selenium premix provided 0.2 ppm Se.

[4] Monensin was included at 99 mg/kg (Coban 90, Elanco Animal Health, Indianapolis IN, USA).

Table 4-2. Effect of dietary coarse corn inclusion (CC) and litter type on feed intake (FI), BW, and adjusted feed conversion ratio (AdjFCR) of broilers from 0 to 49 d of age

CC[*1]	Litter Type[1]	n	Feed Intake			BW			AdjFCR[2]		
			14 d	35 d	49 d	14 d	35 d	49 d	14 d	35 d	49 d
Interaction Effects[1]			(g)						(g feed/g BW gain)		
0%	Old	8	634^{ab}	3870	7373	466	2321	3875	1.47	1.70	1.93
0%	New	8	622^{b}	3803	7284	459	2296	3844	1.47	1.69	1.92
50%	Old	8	621^{b}	3811	7172	465	2353	3863	1.45	1.64	1.88
50%	New	8	639^{a}	3809	7285	467	2354	3935	1.48	1.65	1.88
SEM			6.8	30.0	78.4	3.6	13.2	32.0	0.02	0.01	0.02
Main Effects											
0%		16	628	3836	7328	463	2309^{B}	3860	1.47	1.70^{A}	1.92^{A}
50%		16	630	3810	7228	466	2353^{A}	3899	1.47	1.65^{B}	1.88^{B}
SEM			4.8	21.2	55.4	2.5	9.3	22.7	0.01	0.01	0.01
	Old	16	627	3840	7272	465	2337	3869	1.46	1.67	1.90
	New	16	630	3806	7284	463	2325	3890	1.48	1.68	1.90
	SEM		4.8	21.2	55.4	2.5	9.3	22.7	0.01	0.01	0.01
Source of Variation			*P-Value*								
CC * Litter			0.04	0.29	0.20	0.23	0.35	0.12	0.33	0.36	0.79
CC			0.73	0.39	0.21	0.40	< 0.01	0.22	0.80	< 0.01	< 0.01
Litter Type			0.66	0.27	0.88	0.52	0.38	0.53	0.44	0.69	0.99

[a, b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

[A, B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of old litter or new wood shavings litter and 0 or 50% CC inclusion.

[2] AdjFCR=Feed intake per pen/total BW gain, including BW of mortality that occurred during the time period.

Table 4-3. Effect of dietary coarse corn (CC) inclusion and litter type, and their interaction on absolute and relative weight of proventriculus and gizzard, gizzard:proventriculus ratio (G/P), jejunum and ileum unit weight, and tensile strength at 49 d of age

CC[1]	Litter Type[1]	n	BW	Proventriculus		Gizzard		G/P[2]	Jejunum		Ileum	
									Unit Weight	Tensile Strength	Unit Weight	Tensile Strength
Interaction Effects[1]			(kg)	(g)	(mg/g BW)	(g)	(mg/g BW)	(g/g)	(g/cm)	(N)	(g/cm)	(N)
0%	Old	8	4.08	9.33	2.29	32.25	7.91	3.51	3.03	4.93	2.54	5.40
0%	New	8	4.10	10.12	2.47	33.91	8.27	3.42	3.11	4.14	2.78	5.12
50%	Old	8	4.16	8.79	2.11	37.72	9.07	4.35	2.73	4.69	2.46	5.52
50%	New	8	4.09	9.93	2.43	38.23	9.34	3.92	2.73	4.55	2.59	5.08
SEM			0.04	0.47	0.10	1.12	0.28	0.11	0.12	0.34	0.12	0.30
Main Effects												
0%		16	4.09	9.72	2.38	33.08^{B}	8.11^{B}	3.46^{b}	3.07^{A}	4.54	2.66	5.29
50%		16	4.13	9.36	2.27	37.98^{A}	9.21^{A}	4.13^{a}	2.73^{B}	4.62	2.52	5.30
SEM			0.26	0.32	0.07	0.79	0.20	0.17	0.09	0.24	0.09	0.22
	Old	16	4.12	9.06^{b}	2.20^{b}	34.99	8.49	3.93	2.88	4.81	2.50	5.46
	New	16	4.10	10.02^{a}	2.45^{a}	36.07	8.77	3.66	2.92	4.35	2.68	5.10
	SEM		0.26	0.32	0.07	0.79	0.20	0.17	0.09	0.24	0.08	0.22
Source of Variation								*P-Value*				
CC * Litter Type			0.21	0.71	0.52	0.61	0.86	0.34	0.74	0.34	0.61	0.79
Litter Type			0.52	< 0.05	0.03	0.33	0.26	0.76	0.76	0.17	0.13	0.24
CC			0.25	0.44	0.30	< 0.01	< 0.01	0.01	< 0.01	0.80	0.25	0.89

[a, b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

[A, B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of old litter or new wood shavings litter and 0 or 50% CC inclusion.

[2] G/P=gizzard/proventriculus ratio.

Table 4-4. Effect of dietary coarse corn (CC) inclusion and litter type, and their interaction on litter nitrogen (N), moisture, and pH of broilers at 45 d of age

CC[1]	Litter Type[1]	n	Nitrogen	Moisture	pH
Interaction Effects[1]				(%)	
0%	Old	8	3.94^{A}	37.32	8.28
0%	New	8	3.62^{B}	34.41	8.45
50%	Old	8	3.44^{B}	38.66	8.44
50%	New	8	3.48^{B}	38.40	8.45
SEM			0.06	1.57	0.04
Main Effects					
0%		16	3.78^{A}	35.87	8.36^{b}
50%		16	3.46^{B}	38.53	8.45^{a}
SEM			0.04	1.07	0.03
	Old	16	3.69^{a}	37.99	8.37
	New	16	3.55^{b}	36.41	8.44
	SEM		0.04	1.07	0.03
Source of variation				*P-Value*	
CC * Litter Type			< 0.01	0.37	0.09
Litter Type			0.03	0.29	0.09
CC			< 0.01	0.08	< 0.05

$^{a, b}$ Means within a column with different superscripts differ significantly ($P \leq 0.05$).

$^{A, B}$ Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of old litter or new wood shavings litter and 0 or 50% CC inclusion.

Table 4-5. Effect of dietary coarse corn (CC) inclusion and litter type, and their interaction on broilers apparent ileal digestibility of nitrogen (N) and energy at 49 d of age

CC[1]	Litter Type[1]	n	Nitrogen	Energy
Interaction Effects[1]			(% digestibility)	
0%	Old	8	73.57	62.99
0%	New	8	74.46	60.78
50%	Old	8	77.52	66.84
50%	New	8	75.69	65.31
SEM			1.08	1.25
Main Effects				
0%		16	74.02^{b}	61.88^{B}
50%		16	76.60^{a}	66.07^{A}
SEM			0.77	0.89
	Old	16	75.55	64.91
	New	16	75.08	63.04
	SEM		0.77	0.89
Source of Variation			*P-Value*	
CC * Litter Type			0.22	0.79
Litter Type			0.67	0.15
CC			0.03	<0.01

[a, b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).
[A, B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).
[1] Treatments consisted of old litter or new wood shavings litter with 0 or 50% CC inclusion.

Table 4-6. Effect of dietary coarse corn (CC) inclusion and litter type, and their interaction on broiler jejunum morphology at 49 d of age

CC[1]	Litter[1]	n	Tip width	Villus Height	Base width	Crypt Depth	Muscularis layer	Surface Area	V/C[2] Ratio
Interaction Effects[1]					(μm)			$(\mu m^2 \times 10^{-3})$	
0%	Old	8	204^{b}	1736^{B}	272	263	379	414^{B}	6.6
0%	New	8	140^{c}	1508^{B}	215	195	344	268^{C}	7.7
50%	Old	8	207^{b}	1335^{C}	271	229	291	319^{B}	5.8
50%	New	8	255^{a}	2181^{A}	316	208	315	622^{A}	10.5
SEM			15.7	51.2	22.1	21.5	16.4	24.8	0.4
Main Effects									
0%		16	172^{b}	1622	244	229	361^{a}	337^{B}	7.2
50%		16	231^{a}	1758	294	218	303^{b}	461^{A}	8.2
SEM			16.5	72.6	19.3	33.4	19.2	31.6	0.7
	Old	16	206	1536^{b}	272	246	335	367^{b}	6.2^{b}
	New	16	197	1844^{a}	266	202	329	427^{a}	9.1^{a}
	SEM		16.5	72.6	19.3	33.4	19.2	31.6	0.7
Source of variation						*P-value*			
CC * Litter Type			< 0.04	< 0.01	0.10	0.89	0.33	< 0.01	0.73
Litter Type			0.62	0.04	0.37	0.41	0.72	< 0.01	< 0.01
CC			0.03	0.13	0.24	0.44	0.02	0.04	0.06

[a-b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

[A-B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of old litter or new wood shavings litter and 0 or 50% CC inclusion.

[2] V/C=villus height:crypt depth ratio.

Table 4-7. Effect of dietary coarse corn (CC) inclusion and litter type, and their interaction on broiler ileum morphology at 49 d of age

CC[1]	Litter[1]	n	Tip width	Villus Height	Base width	Crypt Depth	Muscularis layer	Surface Area	V/C[2] Ratio
Interaction Effects[1]					(μm)			($\mu m^2 \times 10^{-3}$)	
0%	Old	8	164	997	194	159	311	178	6.3
0%	New	8	195	1061	255	136	264	239	7.8
50%	Old	8	203	791	214	134	264	202	5.9
50%	New	8	181	1070	195	182	284	165	5.9
SEM			15.5	36.6	20.5	17.0	23.9	25.8	0.4
Main Effects									
0%		16	179	1029	225	148	287	208	7.0
50%		16	192	931	205	158	274	185	5.9
SEM			19.5	50.2	24.5	20.1	33.2	35.4	0.7
	Old	16	192	931^b	205	158	274	185	6.1
	New	16	188	1066^a	225	159	274	220	6.8
	SEM		19.5	50.2	24.5	20.1	33.2	35.4	0.7
Source of variation						*P-value*			
CC * Litter Type			0.32	0.51	0.51	0.34	0.19	0.06	0.12
Litter Type			0.38	0.02	0.24	0.71	0.89	0.72	0.31
CC			0.79	0.06	0.32	0.39	0.91	0.35	0.44

[a-b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

[A-B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of old litter or new wood shavings litter and 0 or 50% CC inclusion.

[2] V/C=villus height: crypt depth ratio.

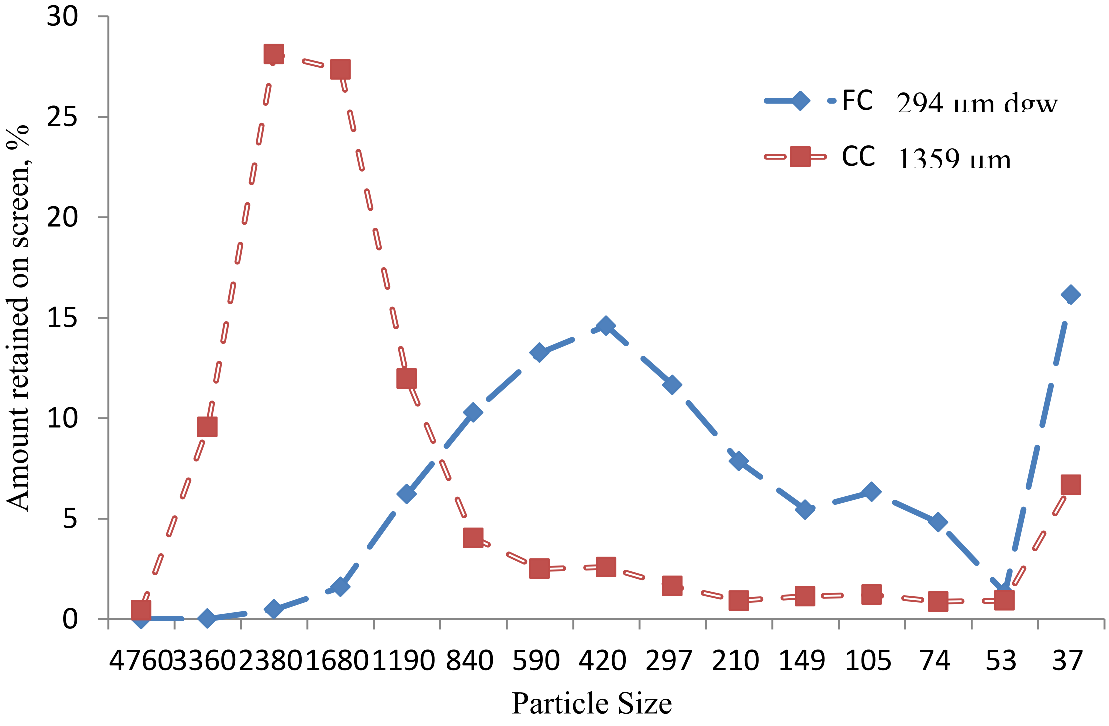

Figure 4-1. The geometric mean diameter by mass (dgw) and particle size distribution of fine corn (FC) and coarse corn (CC)

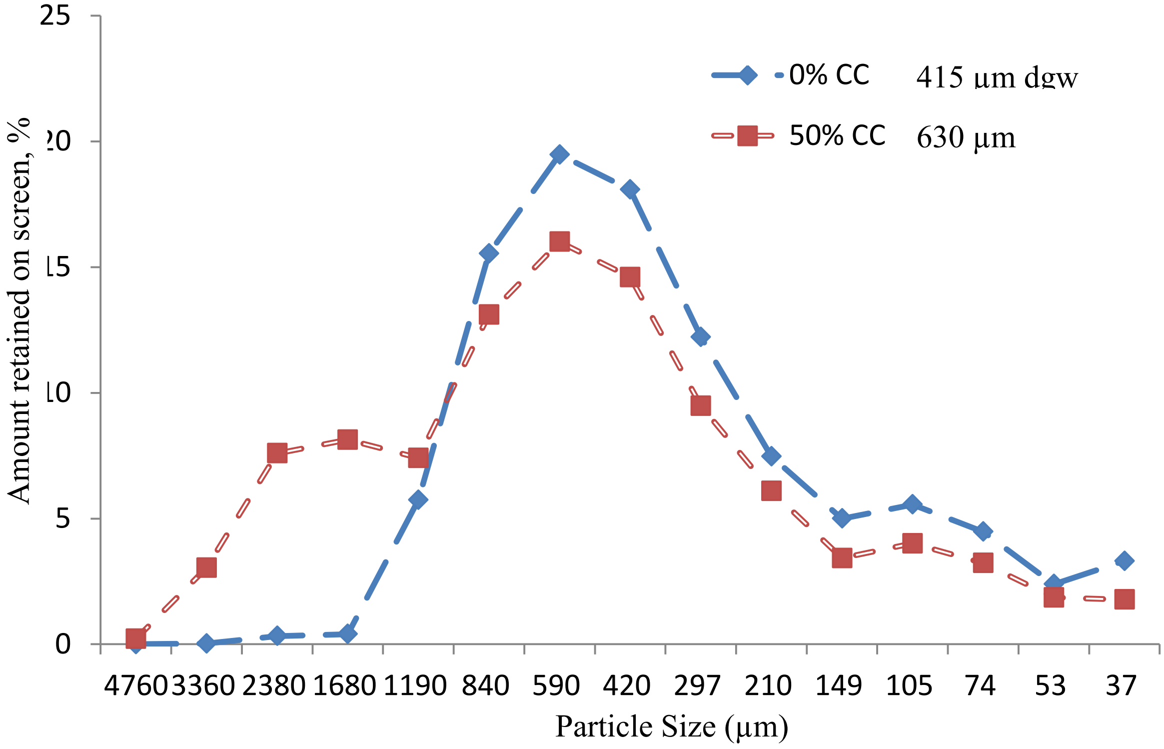

Figure 4-2. The geometric mean diameter by mass (dgw) and particle size distribution of mash diets prior to pelleting with 0 and 50% coarse corn (CC) replaced fine corn (FC)

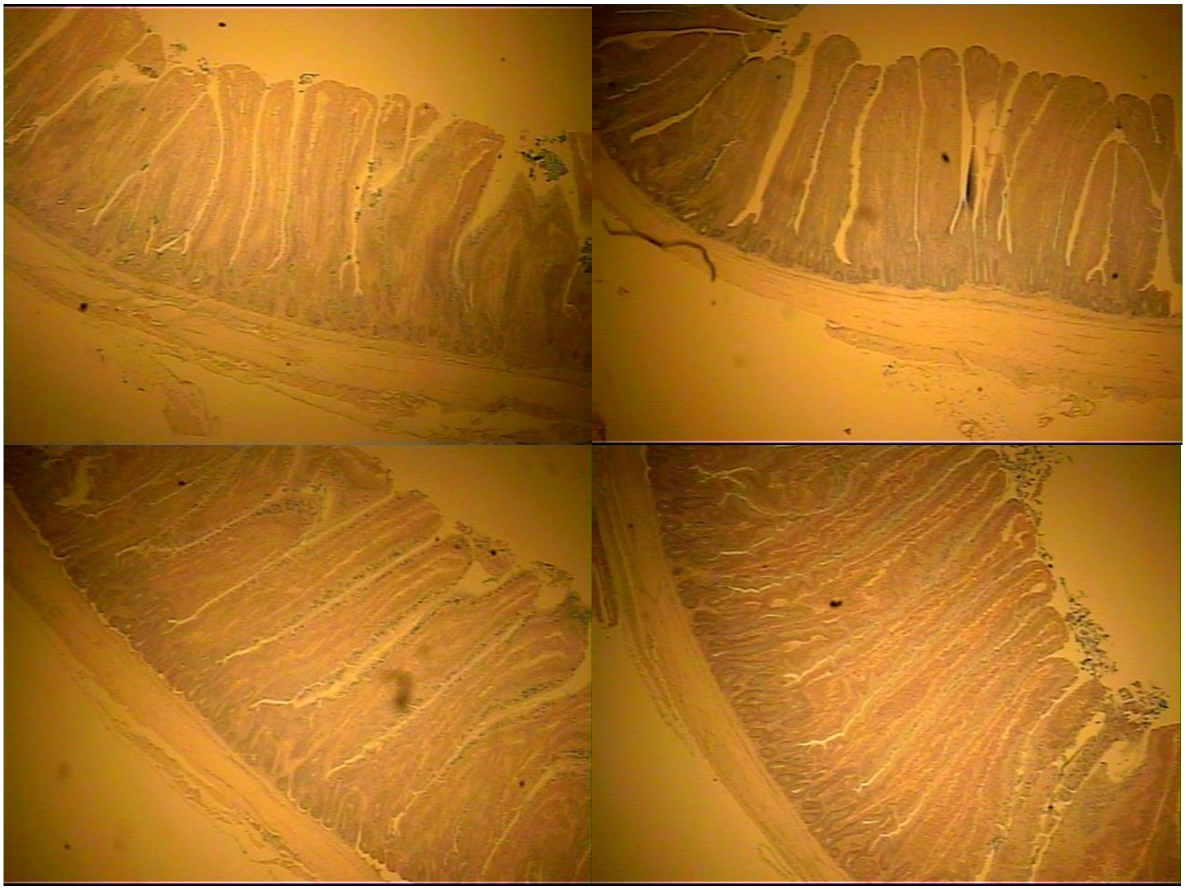

Figure 4-3. The influence of coarse corn (CC) inclusion and litter type on jejunum and ileum villus structure
Top left: Ileum villus, 0% CC old litter.
Top right: Ileum villus, 50% old litter.
Bottom left: Jejunum villus, 0% CC new litter.
Bottom right: Jejunum villus, 50% CC new litter.

CHAPTER 5

Effect of Dietary Coarsely Ground Corn on Broiler Live Performance, Gastrointestinal Tract Development, Apparent Ileal Digestibility of Energy and Nitrogen, and Digesta Particle Size Distribution and Retention Time

ABSTRACT

Dietary structural material, such as roller mill coarsely ground corn (CC), has been reported to improve broiler live performance, but limited research has been carried out regarding optimum dietary CC inclusions and its influence on broiler gastrointestinal tract (GIT) function and development. In this 45 d cage study, the effects of dietary CC inclusion on broiler live performance, GIT development, apparent ileal digestibility (AID) of energy and nitrogen (N), and digesta particle size distribution and retention time were investigated. This study was a single factor experiment of three CC inclusions (0, 25, and 50% fine corn (FC) replaced by CC), and there was 6 replicate pens with 10 birds per cage in each treatment. AdjFCR at 35 and 42 d ($P < 0.01$) was improved as the dietary inclusion levels of CC increased without an effect on feed intake. Broilers fed 50% dietary CC inclusion had increased absolute and relative gizzard weight at 42 d of age as compared to those fed diets with 0 and 25% dietary CC inclusion ($P < 0.01$). Moreover, and dietary inclusion of CC increased absolute proventriculus weight at 28 d of age ($P < 0.05$), but did not influence relative pancreas weight. Only a numerically lower pH of proventriculus digesta and a decreased tendency of gizzard digesta pH were observed at 28 d of age in this study, and there was no difference in jejunum and ileum digesta pH at 28 or 42 d of age. The 25 and 50% dietary CC inclusion level treatment increased the digesta retention time at 30 and 45 d of age ($P < 0.05$ and $P < 0.01$, respectively). The 25% and 50% dietary CC inclusion improved AID of energy by 7.1 and 8.2 %, respectively, when compared with the 0% CC treatment, as well as 12.2 and 12.4% for AID of nitrogen. The digesta particles in the

jejunum had a similar distribution and a dgw of 218, 204, and 181 µm with 0, 25, of 50% CC inclusion, respectively. In conclusion, birds fed pelleted and screened diets that contained 25% and 50% CC exhibited increased BW, improved feed efficiency, and increased AID of energy and N, which was probably due to enhanced gizzard development and greater digesta retention time.

INTRODUCTION

Feed particle size reduction has long remained the central paradigm of feed milling, but feed particle size plays a paradoxical role in poultry nutrition. From a feed manufacturing perspective, smaller feed particle size has been found to improve mixing efficiency and uniformity, reduce ingredient segregation during handling, and improve the efficiency and quality of feed pellet processing. However, grinding corn to a finer consistency also increases grinding costs (Behnke, 2001). From a nutritional perspective, smaller particle grind size increases relative surface area, which improves digestibility by exposing ingredient substrates to digestive enzymes, and it reduces selective feeding by the animal. However, birds have an instinctive preference for coarse feed particles to stimulate gizzard function, which has been suggested to set the pace of gut motility (Ferket, 2000).

A fully functional gizzard has been thought to improve nutrient digestibility though enhanced gastrointestinal tract (GIT) function and greater digesta retention time (Amerah et al., 2008). Broiler growth and feed efficiency largely depends upon GIT function, which functions to extract nutrients from feed. GIT development, enteric integrity, digestive function, maintenance requirements, and digesta retention time have all been reported to be influenced by enhanced gizzard activity, which has been reported to respond quickly to changes in feed structural characteristics under certain circumstances (Hetland et al., 2002; 2003; Gabriel et al., 2003; 2008; Senkoylu et al., 2009). The importance of physical structure of the diet as a means to improve feed efficiency and live performance has become increasingly recognized, and coarser feed structure has exhibited a positive influence on nutrient digestibility and animal live performance (Nir et al., 1995; Amerah et al., 2008; Samu et al., 2010). A better understanding of the interaction of feed structure with GIT development and its function has become critical for the optimization of feed manufacturing strategies and broiler live performance.

The objectives of the current study were to evaluate the effects of dietary inclusion of roller milled coarsely ground corn (CC) on broiler live performance, GIT development and function, apparent ileal digestibility (AID) of energy and nitrogen (N), and digesta particle size distribution and retention time.

MATERIALS AND METHODS

Feed Formulation, Manufacture, and Experiment Design

Corn-soy broiler diets (Table 5-1) were formulated and manufactured at the North Carolina State University Feed Mill Education Unit to meet or exceed the NRC suggested requirements of broilers (NRC, 1994). The same crumbled starter diet was used for all birds, while three CC inclusion levels in the grower and finisher diets were produced by replacing 0, 25, or 50% of fine corn (FC) with CC. The FC and soybean meal were ground with a hammermill (Model 1522, Roskamp Champion, Waterloo, IA) equipped with two 2.4 mm screens, while the CC was ground with a two-pair roller mill (Model C128829, RMS, Tea, SD) with a gap setting of 0% opening on the top pair of rollers and 100% opening on the bottom pair of rollers. Dry ingredients were blended in a double ribbon mixer (TRDB126-0604, Hayes & Stolz Ind. Mfg. Co., Fort Worth, TX) to produce the mash diet, which was then conditioned at 85°C for 45 seconds and then pelleted with a ring die (4.4 mm by 35 mm) pellet mill (Model PM1112-2, California Pellet Mill Co., Crawfordsville, IN). Pellets were cooled with ambient air in a counter-flow cooler (Model VK09 × 09KL, Geelen Counterflow USA Inc., Orlando, Florida). The starter feed was provided as crumbles and subsequent feeds were fed as pellets with fines removed with a pellet screener (Model 35/7 Roto-Shaker, Sprout Bauer Inc., Muncy, PA). Particle size distribution was determined by ASAE standard S319.3 and the pellet durability index was determined by ASAE standard S269.4.

Husbandry Practices

The care of the birds in the study conformed to the Guide for Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010). A total of 180 Ross 344 × 708 (Aviagen, Huntsville, AL) 1-d-old male broiler chicks were feather sexed, weighed, and randomly distributed among 18 cages within three custom-designed brooding battery cages (Alternative Design, Siloam Springs, AR 72761) in an environmentally controlled room. Care was taken to distribute incubator tray position effects uniformly among all of the broiler pens. Each pen was 61 cm in width, 46 cm in length, and 61 cm in height. Each cage was randomly assigned to one of three dietary treatments (0, 25, or 50% CC) with a total of six replicates per treatment. The chicks were given a budget of 0.9, 2.7, and 3.6 kg starter, grower, and finisher diet, respectively. Each cage had two nipple drinkers and one feeder for *ad libitum* consumption of feed and water, respectively. The lighting program consisted of 23 h of light and 1 h of darkness for the 42 d experimental period. The room temperature was 35°C from 1 to 2 d, 32 to 33°C from 3 to 7 d, 30 to 32°C from 8 to 15 d, and then 22 to 30°C from 16 to 45 d.

Data Collection

Initial pen group BW was determined at placement. Feed intake and BW by cage were recorded at 14, 28, 35, and 42 d of age. Birds were observed twice daily and mortalities were removed and weighed to calculate adjusted feed conversion ratio (AdjFCR). One bird at 28 d and two birds at 42 d of age were weighed individually, and gizzard and proventriculus excised. Each organ was trimmed of surrounding fat, its digesta contents removed, rinsed in water and blotted dried, and then weighed. The organ weights were expressed as a percentage of BW (mg/g BW). The pH of the gizzard and proventriculus contents was measured with a portable pH meter (HACH IQ150 pH/mV/Temperature System). Viscera were excised and gut section (duodenum, jejunum, ileum, and colon) lengths, as well as total gut length (from gizzard pylorus to distal colon) were measured. A 15 cm section of jejunum and ileum were excised, digesta content removed, and fat trimmed before tensile strength measurement using an Instron Tensile Tester 5542 w/ 50N load cell (Instron Corp., Norwood, MA) and Bluehill 2 software for data collection and analysis (Instron proprietary software). The particle size distribution of jejunum digesta content was measured with a Laser Diffraction Particle Size Analyzer (Beckman Coulter, Inc., Brea, CA, Model LS^{TM} 13 320).

Celite^{TM} was added to the finisher diet as an indigestible marker to determine apparent ileal digestibility (AID) of energy and nitrogen (N). At 50 d of age, 3 birds of average BW were necropsied to collect ileal content. Ileal content was analyzed for moisture (Method 934.01, AOAC, 2006a), crude protein (Method 990.03, AOAC, 2006b), acid insoluble ash (Vogtmann et al., 1975), and gross energy (Merrill and Watt, 1973). Gross energy was determined using an adiabatic bomb calorimeter (Model C5003, IKA, Wilmington, NC). Apparent ileal digestibility of energy and N were calculated using the following equation:

$$AID = 100\% - [(ID \times AF) / (AD \times IF)] * 100\%$$

Where:

AID = Apparent ileal digestibility (%)

ID = Marker concentration in diet (%)

AF = Energy or N concentration in ileal digesta (%)

AD = Energy or N concentration in diet (%)

IF = Marker concentration in ileal digesta (%)

Digesta retention time was determined at 30 and 45 d of age. After a 12 h feed withdrawal period, one bird per cage was orally administered a capsule that contained 85 mg chromium oxide as an indigestible marker and then the birds were returned to *ad libitum* feeding. One hour after the gelatin capsule was administrated, feces were observed every 15 min, and the time of the appearance of entirely green colored feces was recorded as the passage time.

Statistical Analysis

Results were analyzed as a one-way treatment structure using a completely randomized design of CC inclusions (0, 25, or 50%). The cage served as the experimental unit for the statistical analysis of the live performance data. All data were analyzed using PROC GLM (Version 9.1, SAS Institute Inc., Cary, NC). Differences were considered significant at $P < 0.05$ or $P < 0.01$, and the differences between means were separated by least significant difference.

RESULTS AND DISCUSSION

The geometric mean diameter by mass (dgw) and particle size distribution of FC, CC, and mash diets prior to pelleting with 0, 25, and 50% CC replacing FC are shown in Figures 5-1 and 5-2. The dgw of FC, CC, SBM, and DDGS prior to mixing were 294, 1362, 491, and 414 µm, respectively. As the 0, 25, and 50% CC replaced FC in the diets, the dgw of mash diets prior to pelleting increased from 432, 541, to 640 µm, respectively. The hammermill and roller mill are two commonly used grinding devices to reduce the particle size of feed grains. Hammermill grinding creates a wider particle size distribution than roller mill grinding (Nir et al., 1995). By blending corn ground by these two grinding devices, we were able to produce a biphasic distribution of particle size, such that the larger particles could stimulate gizzard function, and the smaller particles to help maintain pellet quality and improve digestion and nutrition absorption. Pellet quality of the 0, 25, and 50% CC diets, as determined by the Pellet Durability Index (PDI), were 92, 93, and 90%, with a pellet production rate of 522, 454, and 438 kg/h, respectively. As demonstrated by Angulo et al.

(1996), we observed that pellet durability was inversely related to particle size, likely because smaller particles have more contact points for pellet agglomeration (Behnke, 2001). However, particle size is not the only factor that has been reported to influence pellet quality. Thomas et al. (1997) and Briggs et al. (1999) reported that ingredient composition, steam condition, production output, and die and roller parameters greatly influenced final pellet quality.

The effects of dietary inclusion of CC on feed intake, BW, and adjusted feed conversion ratio (AdjFCR) of broilers are shown in Table 5-2. There were no significant treatment effects on growth performance parameters at 14 d of age. The FI of the birds were similar among all treatments, but higher BW was obtained at 28, 35, and 42 d of age ($P < 0.05$) when birds were fed 25% and 50% CC. Improved AdjFCR were observed at 35 d and 42 d for the birds fed the 25 and 50% CC as compared to those fed 0% CC ($P < 0.01$), respectively. Inconsistent results of the influence of corn particle size on broiler live performance have been reported to be due to difference in feed forms (Reece et al., 1985; Chewning et al., 2012), corn dgw and particle size distribution (Reece et al., 1986; Dozier et al., 2006), and pellet quality (Parsons et al., 2006). Lott et al. (1992) observed improved broiler live performance when corn particle size decreased from 1173 to 710 µm, but Nir (1994) reported improved broiler live performance when corn particle size increased from 525 to 897 µm. Reece et al. (1986) reported both fine (679 µm) and coarse (1289 µm) corn improved BW gain and feed efficiency as compared to medium ground corn (987 µm). They also found that broilers fed a pelleted diet containing 50% FC and 50% CC combination (908 µm) performed better than those fed medium ground corn (987 µm), confirming particle size distribution was important. In contrast to a similar management scenario in our previous study, in which dietary inclusion of 50% CC decreased feed intake and BW at 14, 28, and 35 d, we observed similar feed intake and improved live performance in the current study when a single crumbled starter (0 to 14 d) without CC inclusion and thereafter 100% pellets (15 to 49 d) with 50% CC inclusion. This observation indicated that broiler chicks may not have the gizzard capacity to fully utilize a diet containing 50% CC at an early age (Lily et al., 2011). Moreover, pellet quality could be a confounding factor that was inversely related to CC inclusion.

The effects of dietary CC inclusion on relative gizzard and proventriculus weight, and gizzard:proventriculus ratio are shown in Table 5-3. The 50% dietary CC treatment resulted in a marginal increase in absolute gizzard weight at 28 d of age as compared to the 0% CC inclusion treatment ($P = 0.09$), and it increased both absolute and relative gizzard weight at 42 d of age as compared to the 0% and 25% CC inclusion treatments ($P < 0.01$). Dietary inclusion of 25% and 50% CC increased absolute proventriculus weight at 28 d of age as compared to the 0% CC inclusion level ($P < 0.05$), but no differences were observed for absolute and relative proventriculus weight at 42 d of age. Gizzard:proventriculus ratio was increased at 42 d of age by 25% and 50% CC inclusion as compared to the 0% CC inclusion level ($P < 0.01$). However, dietary CC inclusion did not affect the absolute or relative pancreas weight at 42 d of age. Several researchers have reported that gizzard weight increased as corn particle size increased, independent of the physical form of the diet (Olver et al., 1997; Dahlke et al., 2003). Parsons et al. (2006) reported that gizzard weight and relative gizzard weight increased as corn particle size increased (from 781, 950, 1,042, 1,109, to 2,242 µm). Healy (1992) reported increased weights of gizzard and proventriculus for broilers fed 900 µm corn as compared to those fed 300 µm corn. Furthermore, Gabriel et al. (2008) reported that dietary whole wheat inclusion increased pancreas weight by 12%. Apparently, birds can adjust their mechanical and enzymatic digestion according to feed structure.

The effect of dietary inclusion of CC on digesta pH and intestinal length at 28 and 42 d of age are shown in Table 5-4. Only a numerically lower pH of proventriculus digesta and pH decreased tendency of gizzard digesta were observed at 28 d of age in this study. There was no difference of jejunum and ileum digesta pH at 28 or 42 d of age. Intestinal segment length, as well as the total length:BW ratio, was not influenced by dietary CC inclusion at 42 d of age. Several reports demonstrated dietary structure as coarse grain or fiber can decrease the pH of gizzard contents by a magnitude of between 0.2 and 1.2 units (Dahlke et al., 2003; Gabriel et al., 2003; Engberg et al., 2004; Senkoylu et al., 2009). The diet nutrient composition, water, and feed consumption, and an animal’s tightly regulated acid-base balance are major confounding factors that may hinder the observation of statistically significant pH change.

There are conflicting reports of how coarse diet structure modifies the relative size of intestinal segments. Amerah (2007) reported that all gut segments were shorter in birds fed coarsely ground grain particles than those fed finer grain particles in a mash diet, but there were no differences found in gut length when a pelleted feed form was used. Taylor and Jones (2004) found greater duodenum length with whole wheat (200 g/kg in pelleted diet), but no difference in duodenum weight. We did not observe any difference in gut segment length, which may be due to a 45 d old broiler having a relatively mature body size.

The effect of dietary CC inclusion on intestinal tensile strength at 28 and 42 d, digesta retention time at 30 and 45 d, and apparent ileal digestibility (AID) of energy and nitrogen at 50 d of age are shown in Table 5-5. Dietary inclusion of 50% CC was intended to increase the tensile strength of the ileum at 28 d of age as compared to the 0% CC treatment. The 25 and 50% dietary CC inclusion increased the digesta retention time at 30 and 45 d of age ($P < 0.05$ and $P < 0.01$, respectively), but there was no difference between these two CC treatments. In comparison to the 0% inclusion treatment, 25% and 50% dietary CC inclusion treatments improved AID of energy by 7.1 and 8.2 %, and improved AID of nitrogen by 12.2 and 12.4 %, respectively; but there was no difference between the 25 and 50% CC inclusion treatments. We hypothesized that dietary inclusion of larger feed particles increased intestinal tensile strength due to increased muscular activity associated with reverse peristalsis (Savage, 1995; Sacranie, 2006). However, Dozier et al. (2006) reported that intestinal tensile strength was not affected by dietary CC treatments (15, 25, and 35% CC). The increased digesta retention time we observed in birds fed diets with coarse feed particles corroborated with many other research reports. Larger particles have been reported to be retained within the digestive tract longer than fine particles (Nir et al., 1994b; Denbow, 2000) because coarse feed particles need to be ground to a certain critical size before they can be expelled from the gizzard (Clemens et al., 1975; Moore et al., 1999). A number of studies have shown improved nutrient utilization when birds were fed structural material in their inclusion diet (Preston et al., 2000; Svihus and Hetland, 2001; Rougiere et al., 2009). Parsons (2006) reported coarse grinding of corn increased the efficiency of dietary N and lysine retention in broilers. The improved digestibility of nutrients may arise from the lower digesta pH and greater retention time caused by dietary CC inclusion.

The dgw and particle size distribution of jejunum digesta at 45 d are shown in Figure 5-3. The dgw of jejunum digesta was 218, 204, and 181 μm with 0, 25, and 50% CC inclusion, respectively. Furthermore, these three treatments had similar jejunum digesta particle size distribution. Clemens et al. (1975) and Moore (1999) reported that coarse feed particles needed to be ground to a certain critical size before they could pass from the gizzard. Fernando et al. (1987) suggested that the threshold particle size was between 500-1500 μm before leaving the gizzard in chickens. Hetland et al. (2002 and 2003) and Amerah et al. (2008) reported that a majority of the particles entering the duodenum were smaller than 100 μm, even when considerable amounts of whole wheat or coarse grain particles were added to the diet.

In conclusion, pelleted and screened diets (100% pellets) that contained CC exhibited greater BW and improved AdjFCR with no difference in FI, and increased gizzard weight and gizzard:proventriculus ratio. Dietary inclusion of CC will modulate GIT function, as evidenced by reduced gizzard pH and greater GIT retention time.

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Table 5-1. Ingredient composition and calculated analysis for broiler starter, grower, and finisher diets

Item	Starter	Grower	Finisher
Ingredient		%	
Corn	50.51	54.19	61.20
Soybean meal (48% CP)	33.79	23.22	16.07
Distiller's dried grains with soluble	6.00	15.00	15.00
Poultry byproduct meal	2.00	1.00	1.00
Limestone	0.97	0.93	0.95
Dicalcium phosphate, 18% P	1.93	1.41	1.46
DL-Methionine	0.28	0.13	0.10
L-Lysine	0.12	0.22	0.28
Threonine	0.12	0.12	0.08
Sodium chloride	0.50	0.50	0.50
Vitamin premix[1]	0.05	0.05	0.05
Choline chloride, 60%	0.10	0.10	0.10
Trace mineral premix[2]	0.20	0.20	0.20
Selenium premix[3]	0.10	0.10	0.10
Coccidiostat[4]	0.05	0.05	0.05
Poultry fat	3.23	2.76	2.85
	100.00	100.00	100.00
Calculated analysis			
ME, kcal/g	2.85	2.90	2.95
Protein, %	23.00	20.00	17.00
Calcium, %	1.00	0.80	0.80
Available phosphorus, %	0.50	0.40	0.40
Total lysine, %	1.31	1.13	0.97
Total methionine + cysteine, %	1.00	0.82	0.71

[1] The vitamin premix supplied the following per kg of feed: vitamin A, 6601 IU; cholecalciferol, 1980 IU; niacin, 55 mg; α-tocopheral, 33 mg; pantothenic acid, 11 mg; riboflavin, 6.6 mg; pyridoxine, 4 mg; menadione, 2 mg; thiamin, 2 mg; folic acid, 1.1 mg; biotin, 0.13 mg; and vitamin B12, 0.02 mg.

[2] The mineral premix supplied the following per kg of feed: Zn, 120 mg; Mn, 120 mg; Fe, 80 mg; Cu, 10 mg; I, 2.5 mg; Co, 1.0 mg.

[3] Selenium premix provided 0.2 ppm Se.

[4] Monensin was included at 99 mg/kg. (Coban 90, Elanco Animal Health, Indianapolis IN, USA).

Table 5-2. Effect of dietary coarse corn (CC) inclusion on feed intake, BW, and adjusted feed conversion ratio (AdjFCR) of broilers at 14, 28, 35, and 42 d of age

CC[1]	n	Feed Intake				BW				AdjFCR[2]			
		14 d	28 d	35 d	42 d	14 d	28 d	35 d	42 d	14 d	28 d	35 d	42 d
		(g)								(g/g)			
0 %	6	561	2387	3653	5257	474	1621^{B}	2284^{b}	2929^{b}	1.31	1.77	1.82^{A}	1.94^{A}
25 %	6	570	2406	3670	5350	477	1720^{A}	2400^{a}	3118^{a}	1.32	1.73	1.74^{B}	1.86^{B}
50 %	6	561	2355	3613	5154	469	1696^{A}	2408^{a}	3059^{a}	1.33	1.69	1.69^{B}	1.82^{B}
SEM		8	37	71	113	6	20	31	43	0.02	0.03	0.02	0.02
P-value		0.58	0.56	0.81	0.42	0.53	< 0.01	0.01	0.02	0.65	0.12	< 0.01	< 0.01

[a-b] Means within a column with different superscripts differ significantly ($P < 0.05$).

[A-B] Means within a column with different superscripts differ significantly ($P < 0.01$).

[1] Treatments consisted of diets with 0, 25, or 50% CC inclusion.

[2] AdjFCR=Feed intake per pen/total BW gain, including weights of mortality that occurred during the respective time period.

Table 5-3. Effect of dietary coarse corn (CC) inclusion on absolute and relative weight of gizzard, proventriculus, and pancreas, and gizzard: proventriculus ratio at 28 and 42 d of age

CC^{1}	n	Gizzard				Proventriculus				G/P Ratio		Pancreas	
		28 d	42 d	28 d	42 d	28 d	42 d	28 d	42 d	28 d	42 d	42 d	
		(g)		(mg:g BW)		(g)		(mg:g BW)		(g:g)		(g)	(mg:g BW)
0 %	6	13.47^{y}	20.96^{C}	7.81	6.60^{C}	4.31^{b}	10.26	2.50^{y}	3.26	3.12	2.11^{B}	4.61	1.36
25 %	6	17.46^{xy}	25.73^{B}	10.32	7.63^{B}	5.28^{a}	9.97	3.18^{x}	2.97	3.21	2.84^{A}	4.57	1.30
50 %	6	17.94^{x}	28.34^{A}	9.43	8.75^{A}	5.48^{a}	8.77	2.88^{xy}	2.71	3.28	3.44^{A}	4.72	1.33
SEM		1.46	0.82	0.94	0.35	0.31	0.65	0.19	0.22	0.27	0.17	0.18	0.04
P-value		0.09	< 0.01	0.19	< 0.01	0.04	0.20	0.08	0.20	0.91	< 0.01	0.83	0.67

$^{a-c}$ Means within a column with different superscripts differ significantly ($P < 0.05$).

$^{A-B}$ Means within a column with different superscripts differ significantly ($P < 0.01$).

$^{x-y}$ Means within a column with different superscripts approach significant difference ($P < 0.1$).

^{1} Treatments consisted of diets with 0, 25, or 50% CC inclusion.

Table 5-4. Effect of dietary coarse corn (CC) inclusion on digesta pH and intestinal length at 28 and 42 d of age

CC[1]	n	Digesta pH at 28 d				Digesta pH at 42 d		Intestinal Length at 42 d					
		Proventriculus	Gizzard	Jejunum	Ileum	Jejunum	Ileum	Duodenum	Jejunum	Ileum	Colon	Total Length	Length/ BW
								(cm)					cm/kg
0 %	6	5.43	4.67^{x}	5.86	6.17	6.00	6.32	15.08	75.54	79.58	36.33	185.29	54.49
25 %	6	5.21	4.38^{xy}	5.76	6.22	6.13	6.26	15.96	74.21	77.75	39.08	183.88	52.18
50 %	6	5.11	4.10^{y}	5.82	6.29	6.06	6.36	15.92	75.46	79.17	39.51	186.46	52.70
SEM		0.12	0.16	0.05	0.07	0.11	0.17	0.39	1.11	1.90	0.56	3.29	0.92
P-value		0.20	0.08	0.72	0.55	0.69	0.88	0.21	0.64	0.78	0.20	0.86	0.19

$^{x\text{-}y}$ Means within a column with different superscripts approach significant difference ($P < 0.1$).

[1] Treatments consisted of diets with 0, 25, or 50% CC inclusion.

Table 5-5. Effect of dietary coarse corn (CC) inclusion on intestine tensile strength at 28 and 42 d, digesta retention time at 30 and 45 d, and apparent ileal digestibility of energy and nitrogen at 50 d of age

CC[1]	n	Tensile Strength				Digesta Retention Time		Apparent Ileal Digestibility	
		Jejunum	Ileum	Jejunum	Ileum			Energy	Nitrogen
		28d		42d		30 d	45 d	50 d	
		(N)				(h)		(%)	
0 %	6	2.35	1.90^{y}	2.98	2.43	1.58^{c}	3.54^{B}	54.6^{B}	44.0^{B}
25 %	6	2.10	2.07^{xy}	3.18	2.78	1.75^{b}	4.52^{A}	61.7^{A}	56.1^{A}
50 %	6	2.32	2.69^{x}	3.04	2.65	1.96^{a}	4.32^{A}	62.8^{A}	56.4^{A}
SEM		0.31	0.19	0.56	0.39	0.09	0.27	4.3	6.5
P-value		0.56	0.08	0.66	0.71	< 0.05	< 0.01	< 0.01	< 0.01

$^{a-c}$ Means within a column with different superscripts differ significantly ($P < 0.05$).

$^{A-B}$ Means within a column with different superscripts differ significantly ($P < 0.01$).

$^{x-y}$ Means within a column with different superscripts approach significant difference ($P < 0.1$).

[1] Treatments consisted of diets with 0, 25, or 50% CC inclusion.

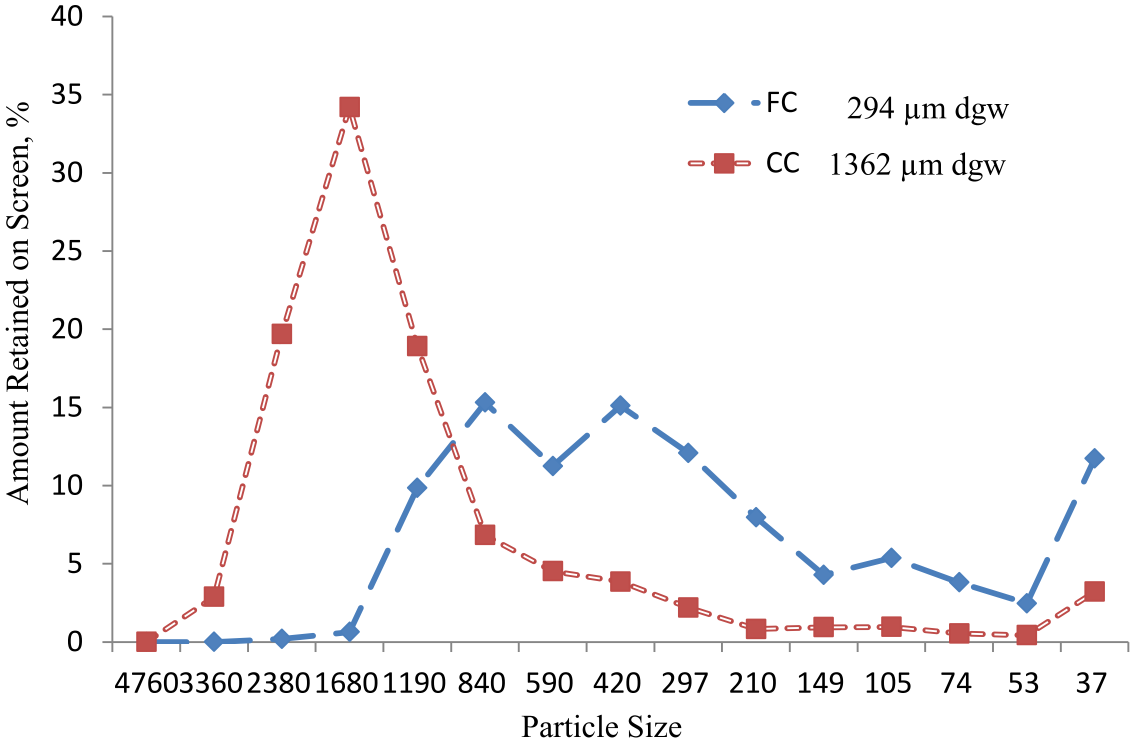

Figure 5-1. The geometric mean diameter by mass (dgw) and particle size distribution of fine corn (FC) and coarse corn (CC) prior to mixing

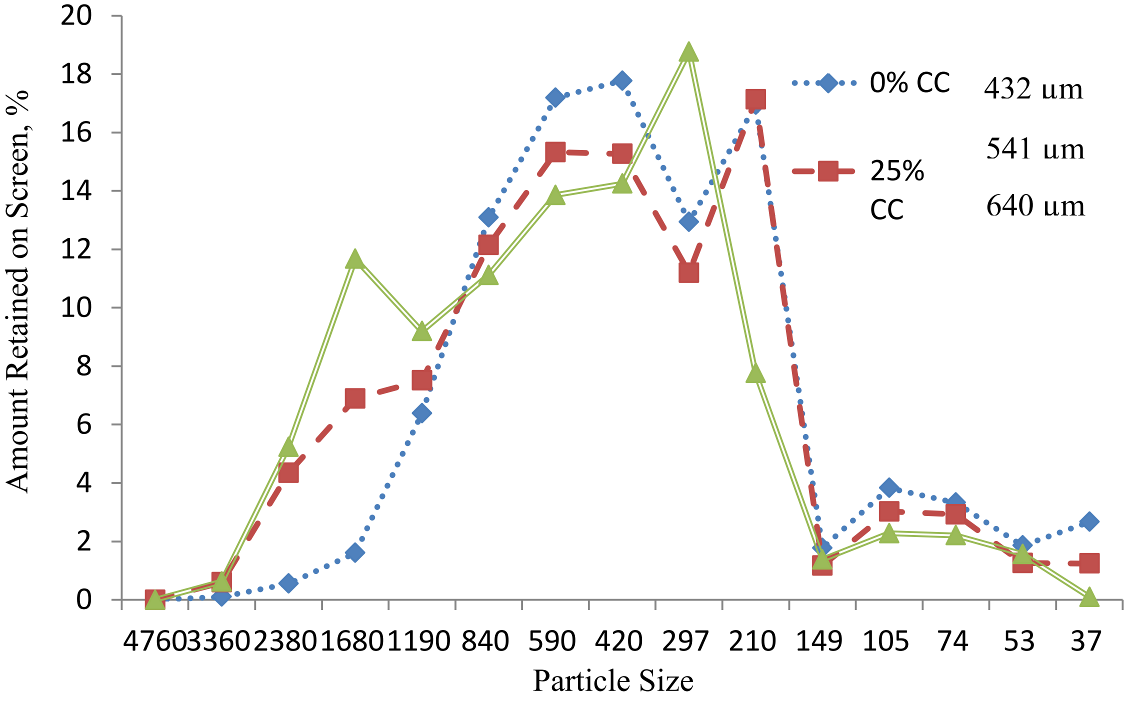

Figure 5-2. The geometric mean diameter by mass (dgw) and particle size distribution of mash diets after mxing but prior to pelleting with 0, 25, and 50% coarse corn (CC) replaced fine corn (FC)

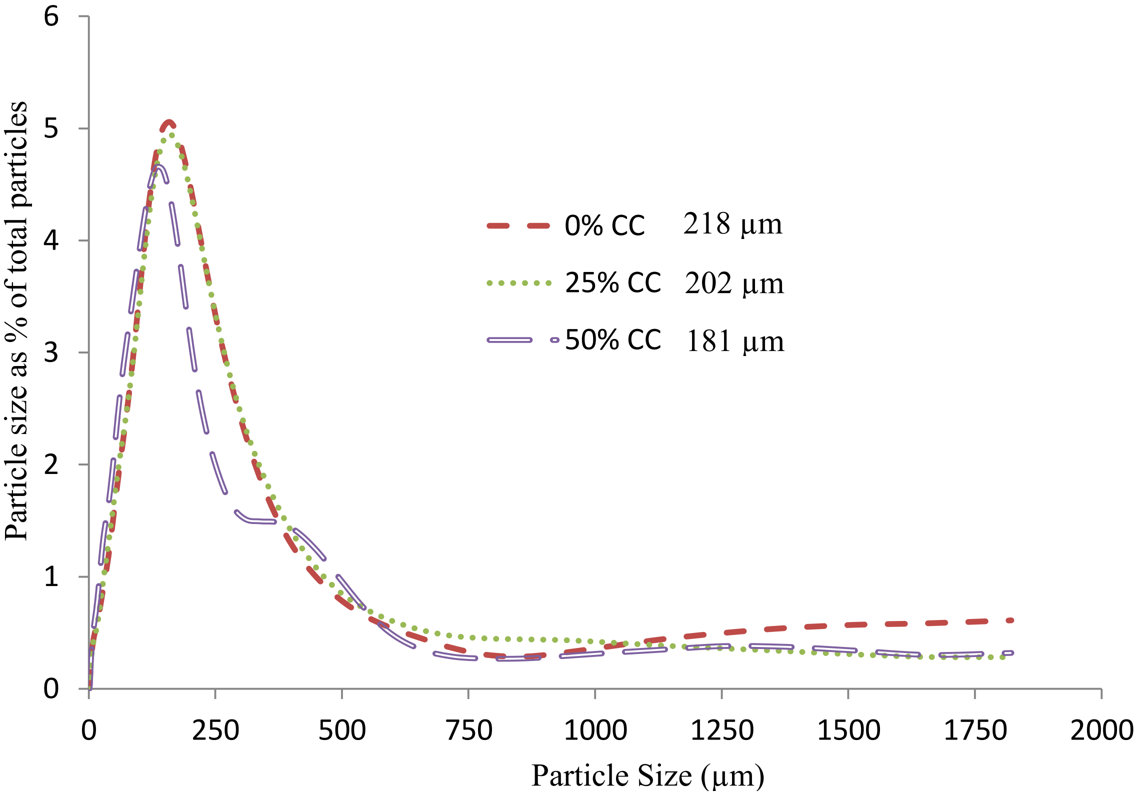

Figure 5-3. The geometric mean diameter by mass (dgw) and particle size distribution of jejunum digesta of birds at 42 d of age fed 0, 25, and 50% coarse corn (CC) diets

CHAPTER 6

Effects of Dietary Coarsely Ground Corn and Floor Type on Broiler Live Performance, Litter Characteristics, Gastrointestinal Tract Development, Apparent Ileal Digestibility of Energy and Nitrogen, and Intestinal Morphology, and Milling Cost

ABSTRACT

The objectives of the present study were to evaluate the effects of dietary CC inclusion and different floor types on broiler live performance, litter characteristics, gastrointestinal tract (GIT) development, apparent ileal digestibility (AID) of energy and nitrogen, intestinal morphology, and milling cost. The experiment was a factorial arrangement of 2 dietary CC inclusions (0 or 50%) and 3 floor types (wire net (WN), new wood shavings litter (NL), or recycled old litter (RL)). A total of 1008 d-old male broiler chicks were randomly assigned to one of 6 treatments with 6 replicate pens per treatment and 28 birds per pen. Fine corn (FC) was produced with a hammermill (271 μm) and the CC was produced with a roller mill (1145 μm). No CC X floor type interaction effects for live performance were observed. The 50% CC inclusion diets increased feed intake at 42 and 49 d ($P < 0.01$), BW from 28 d ($P < 0.01$), and improved AdjFCR from 14 d. WN had greater feed intake at 14 d ($P < 0.01$) than NL and RL. NL and RL increased BW at 28 d as compared to WN, and NL increased BW at 35 d as compared to WN ($P < 0.01$). Dietary inclusion of 50% CC consistently improved AdjFCR after 14 d ($P < 0.01$). NL and RL improved AdjFCR at 14, 28, and 35 d as compared with WN. NL had better 1 to 42 AdjFCR than WN ($P < 0.01$) and better 1 to 49 d AdjFCR than WN and RL ($P < 0.01$). NL and RL had lower 1 to 49 d mortality than WN ($P < 0.05$). Dietary inclusion of 50% CC significantly increased absolute ($P < 0.01$) and relative gizzard weight ($P < 0.01$) and the gizzard:proventriculus ratio ($P < 0.05$) at 28 and 49 d, but decreased absolute and relative proventriculus weight at 49 d ($P < 0.01$). NL increased absolute and relative gizzard weight at 28 d ($P < 0.01$) and 49 d ($P < 0.05$) as compared to

WN. NL decreased absolute proventriculus weight as compared to WN at 28 and 49 d ($P < 0.05$). Consequently, the gizzard:proventriculus ratio was increased by NL at 28 and 49 d of age ($P < 0.01$). At 28 d, the dietary inclusion of 50% CC increased pancreas weight ($P < 0.01$), and WN had greater pancreas weight than RL ($P < 0.05$). Dietary inclusion of 50% CC decreased liver weight at 49 d ($P < 0.05$). The only effect on intestine unit weight (g per cm intestine) was observed on the duodenum weight due to floor type at 14 d of age. NL and RL resulted in greater duodenum unit weight than WN ($P < 0.01$). Dietary inclusion of 50% CC decreased litter moisture at 35 d of age ($P < 0.05$), litter nitrogen at 35 and 49 d ($P < 0.05$), and litter pH at 49 d ($P < 0.05$). The RL treatment had greater litter nitrogen ($P < 0.05$) at 14, 35, and 49 d, and greater litter moisture ($P < 0.05$), litter pH ($P < 0.01$), and ammonia concentration ($P < 0.01$) at 49 d. Dietary inclusion of 50% CC increased gizzard content weight ($P < 0.01$) at 28 d, and decreased gizzard content moisture at 28 and 49 d ($P < 0.01$). The 50% CC treatment also improved apparent ileal digestibility (AID) of nitrogen ($P < 0.05$). Dietary inclusion of 50% CC increased jejunum villi height ($P < 0.01$), surface area ($P < 0.05$), V/C ratio ($P < 0.05$), and ileal villi surface area ($P < 0.05$), but decreased ileal muscularis thickness ($P < 0.05$). NL increased jejunum villi height ($P < 0.05$), surface area ($P < 0.05$), ileal muscularis thickness ($P < 0.05$), but decreased ileal villi surface area as compared to WN ($P < 0.05$). Feed manufacturing electrical costs of the diet containing 50% CC was 23.1% cheaper than 100% fine corn diet. Broilers fed diets containing 50% CC exhibited improved AdjFCR, increased BW, and reduced litter moisture and nitrogen.

Raising broilers on NL resulted in a similar effect as dietary CC, indicating broilers may need a coarse textural component in their diet to facilitate gastric development and function.

INTRODUCTION

Feed costs, production efficiency, gastrointestinal tract (GIT) function and health, and environmental sustainability have been identified as major challenges to the poultry industry. Different strategies have been applied to improve GIT function, but improving poultry GIT function by modifying feed structure could be a cost-effective and simple resolution to many current challenges of poultry broiler production. The successful application of whole wheat in poultry feeds fed to broilers in the EU demonstrate that coarsely ground grain in pelleted feed may improve broiler growth performance and feed conversion ratio (FCR). Structural components, such as whole or coarsely ground grain, has been reported to enhance gizzard activity and modulate GIT function (Svihus, 2002), extend GIT retention time (Hetland et al., 2003; 2005; Gabriel et al., 2008), decrease digesta pH (Gabriel et al., 2003), and alter hind gut bacterial profile (Engberg et al 2004). In agreement, our previous studies demonstrated that dietary inclusion of coarsely ground corn (CC) improved broiler live performance and nutrient digestibility under same pellet quality circumstances through enhanced GIT motility and function. Inclusion of CC in pelleted feed stimulated gizzard function, increased digesta retention time, enhanced reverse peristalsis, and reduced digesta pH, which improved digestion and nutrient absorption. The beneficial effects of CC on digestibility of nutrients may also arise from altered enteric ecosystem, as dietary CC inclusion has been found to influence intestinal villi structure and alter hind gut bacterial population profile (Chapter 3). The effects of structural characteristics of the feed on the enteric ecosystem require further investigation. Moreover, litter nitrogen and moisture has been reported to be reduced by dietary CC inclusion (Chapter 3 and IV).

Insoluble fiber has been shown to influence intestinal physiology and function by enhancing gizzard activity in a manner similar to that of dietary CC inclusion. Inclusion of insoluble fiber in broiler diets has been found to stimulate gizzard function (Svihus et al., 2001), increase the retention time of the digesta (Hetland, 2005), increase acid production by the proventriculus (Duke, 1986), and improve starch digestibility (Hetland and Svihus, 2001). Litter could be a significant but often ignored insoluble fiber source in a floor rearing system, as limited information about its effect on broiler performance is available. However, Hetland et al. (2003) reported that the weights of empty gizzard and gizzard contents were increased due to access to wood shavings.

A better understanding of the interaction between dietary structural material and GIT development and function was deemed to be critical to optimize feed manufacturing strategies and broiler live performance. The objectives were to evaluate the effects of dietary CC inclusion and floor type on broiler live performance, litter characteristics, GIT development, apparent ileal digestibility of energy and nitrogen, and intestinal morphology. Further, the comparative grinding cost of feed by hammermill and roller mill was studied.

MATERIALS AND METHODS

Feed Formulation, Manufacture, and Experiment Design

Corn-soy broiler diets (Table 6-1) were formulated and manufactured at the North Carolina State University Feed Mill Education Unit to meet or exceed the NRC suggested requirements of broilers (NRC, 1994). The CC treatment starter diet was produced by replacing 20% of the total corn with CC in a basal diet that contained finely ground corn (FC), while grower and finisher diets were produced by replacing 50% of the FC with CC. The FC and soybean meal were ground with a hammermill (Model 1522, Roskamp Champion, Waterloo, IA) equipped with two 2.4 mm screens, whereas the CC was ground with a two-pair roller mill (Model C128829, RMS, Tea, SD) with a gap setting of 25% opening on the top and 35% opening on the bottom. Dry ingredients were blended in a double ribbon mixer (TRDB126-0604, Hayes & Stolz Ind. Mfg. Co., Fort Worth, TX) to produce the mash diets that were conditioned to 85°C and pelleted with a pellet mill (Model PM1112-2, California Pellet Mill Co., Crawfordsville, IN) equipped with a ring die (4.4 mm by 35 mm). Pellets were cooled with ambient air in a counter-flow cooler (Model VK09 × 09KL, Geelen Counterflow Inc., Orlando, Florida). The starter diets (0 or 20% CC) were provided as crumbles from 1 to 14 d, and the subsequent grower and finisher diets (0 or 50% CC) were fed as pellets with fines screened and removed with a pellet screener (Model 35/7 Roto-Shaker, Sprout Bauer Inc., Muncy, PA).

Husbandry Practices

This experiment was conducted at the North Carolina State University Chicken Educational Unit. The care of the birds in the study conformed to the Guide for Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010). A total 1,152 Ross 344 ×708 (Aviagen, Huntsville, AL) 1-d-old male broiler chicks were feather sexed, weighed, and placed in a heated and fan-ventilated broiler blackout house until 49 d of age. On the day of hatch, 28 chicks were randomly assigned per pen among 36 pens in total. Care was taken to distribute incubator tray position effects uniformly among all of the broiler pens. Each pen was 1.2 m wide by 1.8 m long. The stocking density was 12.56 chicks/m^2. Each pen contained one bell-type drinker and one tube feeder. Each pen was assigned to one of six treatments as factorial arrangement of 3 floor treatments ((wire net (WN), new wood shavings litter (NL), or recycled old litter (RL)) and 2 dietary CC inclusion levels (0 or 50% CC). Each factorial treatment was assigned to 6 replicates pens. The chicks were given a budget of 0.9, 2.7, and 3.6 kg of starter, grower, and finisher diets, respectively. The birds had *ad libitum* access to water and feed throughout the study.

Feeders were shaken once per day from 1 to 14 d and twice per day from 15 to 49 d to minimize variation in feed intake due to differences in feed flow characteristics. The lighting program was 23 h of light from 1 to 7 d, 22 h of light to 14 d, 20 h of light to 21 d, and natural light from 22 to 49 d of age. The air temperature of the house from placement to 7 d was maintained approximately at 32 to 34°C, 29°C to 14 d, 27 °C to 21 d, and ambient thereafter.

Data Collection

Particle size distribution was determined by ASAE S319.3 and the pellet durability index was determined by ASAE standard S269.4. The electrical consumption of grinding by hammermill and roller mill was measured by monitoring motor power load and production rate during a 4 minute period of grinding, which was replicated 3 times each.

Initial pen group BW was collected at placement. Feed intake and BW by pen were thereafter recorded at 14, 28, 35, 42, and 49 d of age. Birds were observed daily and mortalities were removed and weighed to calculate adjusted feed conversion ratio (AdjFCR). At 14, 28, 35, 42, and 49 d of age, one bird that approximated the average BW per pen was individually weighed, and gizzard, proventriculus, liver, pancreas, and whole gut excised. The fat surrounding those organs and 10 cm of each intestine section (duodenum, jejunum, ileum, and colon) was trimmed, contents removed, rinsed, blotted dry, and weighed. The data was expressed as a percentage of BW (mg/g BW). The pH of the gizzard and proventriculus digesta was measured with a portable pH meter (HACH IQ150 pH/mV/Temperature System) at the time of necropsy. Litter samples were taken on 14, 28, 35, 42, and 49 d of age from six evenly distributed positions within each pen, and mixed to create a composite sample for each pen. The moisture, pH, and nitrogen content were determined for each sample. Moisture was determined by weight loss alter drying at 100°C for 4 hours (Method 934.01, AOAC, 2006a). Litter nitrogen content of the sample was determined by Combustion Analysis (LECO) using AOAC Official Method 990.03 (AOAC, 2006b). The ammonia concentration was measured by Gastec Ammonia Passive Dosi-Tube (No. 3DL, Gastec Corporation, Japan) with a 12 cm diameter and 18 cm height polyester tube placed on the litter at 49 d of age.

Celite^{TM} was added to the finisher diet as an indigestible marker to determine apparent ileal digestibility (AID) of energy and nitrogen. At 50 d of age, 3 birds of average BW were necropsied to collect ileal content. Ileal content was analyzed for moisture (Method 934.01, AOAC, 2006a), crude protein (Method 990.03, AOAC, 2006b), acid insoluble ash (Vogtmann et al., 1975), and gross energy (Merrill and Watt, 1973). Gross energy was determined with an adiabatic bomb calorimeter (Model C5003, IKA, Wilmington, NC). Apparent ileal digestibility of energy and nitrogen were calculated using the following equation:

$$AID = 100\% - [(ID \times AF) / (AD \times IF)] * 100\%$$

Where:

AID = Apparent ileal digestibility (%)

ID = Marker concentration in diet (%)

AF = Energy or nitrogen concentration in ileal digesta (%)

AD = Energy or nitrogen concentration in diet (%)

IF = Marker concentration in ileal digesta (%)

Histological sampling and analysis were conducted with the following procedure. At 50 d of age one bird that approximate the average BW per pen. After an abdominal incision, the intestines were located and middle (5 cm) sections of the jejunum and ileum were collected. The content of each GIT section was gently flushed with a saline solution (NaCl, 0.9%).

Each GIT section sample was fixed in a vial containing a10% formalin. After a period of not less than 48 h, each GIT sample was removed from the formalin solution, and a middle section was dissected (0.5 cm) and stored in an individual histology cassette with proper identification, rinsed in distilled water, and immediately placed in a container with 70% ethanol. All the cassettes (sections) were processed at NCSU Veterinary Medicine Pathology laboratory. Samples were stained with Alcian Blue (pH 2.5) following a standard procedure to make histological slides by the paraffin inclusion method (Weesner, 1960).

Three cross-sections were obtained from each sample for further staining and morphometric evaluation. The slides were examined using an optical microscope (Micromaster, Fisher Scientific, CAT. No. 12-562-27) fitted with a digital camera and the images were analyzed using image analysis software (UTHSCSA Image Tool, version 3.00). Two images of each sample section were captured with a final magnification of 4 × and the thickness of the muscularis, villus height, villus tip and base width, and crypt depth were measured. The surface areas of the villus and crypt were calculated as the product of the height multiplied by the width. An average value was calculated for each GIT segment from each bird. The villus height: crypt depth ratio was then calculated.

Statistical Analysis

This experiment was analyzed as a 2 × 3 factorial arrangement as a randomized complete block design to determine main effects of 2 dietary CC inclusions levels (0 or 50%) and 3 floor types (wire net (WN), new wood shavings litter (NL), and recycled old litter (RL)) and the correspond factorial interaction effects. The pen served as the experimental unit for the statistical analysis of the live performance data. All data were analyzed using PROC GLM of SAS (Version 9.1, SAS Institute Inc., Cary, NC). Differences were considered significant at $P < 0.05$ or $P < 0.01$, and the differences between means were separated by least significant difference.

RESULTS AND DISCUSSION

The geometric mean diameter by mass (dgw) and particle size distribution of FC, CC, NL, RL, and mash diets prior pelleting where 0 or 50% CC replaced FC are shown in Figures 6-1 and 6-2. The dgw of FC, CC, NL, RL, SBM, and DDGS was 271, 1145, 1119, 1167, 513, and 489 µm, respectively, and as 50% CC replaced FC in the diets, the dgw of the grower diet in mash form increased from 414 to 563 µm, and from 448 to 684 µm for finisher diet in mash form. Smaller feed particle size has been found to increase surface area of ingredients, which has been hypothesized to improve digestibility by exposing ingredient substrates to digestive enzymes and improve pellet efficiency and quality. However, coarser feed particle size reduces grinding cost (Table 6-2) and has been reported to enhance gizzard activity, which has been described as the pacemaker of gut motility (Ferket, 2000). The hammermill and roller mill have been used to provide different grain particle size distributions. Hammermill grinding produces a wider particle size distribution than roller mill grinding (Nir et al., 1995). By mixing corn ground by these two grinding methods, we produced a biphasic particle size distribution as shown in Figure 6-3. Thus, the larger particles were provided to stimulate gizzard function and the smaller particles were available for better digestion and nutrient absorption. The inconsistent results of the influence of litter condition on broiler live performance implies that the dgw of litter could be an important factor, which has not been reported previously. In the current study, the particle size of litter should not confound the results from other factors since NL and RL had similar dgw.

The electrical consumption of grinding with hammermill *versus* roller mill is shown in Tables 6-2. The combination of 50% hammermill finely ground corn and 50% roller mill coarsely ground corn decreased electrical costs by 9.47 cents/ton feed ($0.412 *versus* $0.317) as compared to hammermilling all finely ground corn. A similar cost saving by using roller mill coarsely ground corn has been reported by Dozier et al. (2006), where the cost of hammermill grinding of corn to 800 microns was $0.497 per ton, as compared to $0.257 per ton for roller mill corn grinding to 1500 microns. The grinding of whole grain for broiler feeds constitutes the second greatest energy expenditure after pelleting (Reece et al., 1985). The roller mill has not been commonly used in commercial feed production, despite the fact it has a lower energy consumption per ton of feed (Nir et al., 1990) and produces less dust and noise during grinding (Heimann, 2002). Roller mill ground cereals grains are also more uniform and produce less fines than hammermills (Nir et al., 1990, 1995).

Pellet quality, as determined by the PDI, was decreased from 92% to 90% in the grower diet, and decreased from 93% to 92% in the finisher diet, as 50% CC was included in the diet. The percentage of screened fines from the grower diet was 13% in the 0% CC diet *versus* 17% in 50% CC diet, as well as 12% *versus* 19% in the finisher diets, respectively. Amerah (2008) reported finely ground corn (284 μ dgw) resulted in a better pellet durability (94.6 *versus* 92.1%, $P < 0.05$) than coarsely ground corn (890 μ dgw), but Stevens (1987) reported that no significant differences were found in PDI from pellets made with coarse (1023 μ dgw), medium (794 μ dgw), or fine (551 μ dgw) particles of corn. Dietary CC inclusion was observed to create more pellet fines as compared to the FC diet. Previous studies have shown that pellet feed with 15 to 20% fines reduce feed intake, which result in poorer growth performance of broiler (Mckinney et al., 2004; Hu et al., 2012; Chapter 3).

The effects of dietary CC inclusion and floor type on feed intake and BW to 49 d of age are shown in Table 6-3. No diet × litter interaction effects were observed. The 20% dietary CC inclusion did not influence the feed intake from 1 to 14 d of age, but the 50% dietary CC inclusion pelleted and screened diets increased feed intake from 35 to 42 and 43 to 49 d of age ($P < 0.01$). There was no treatment effect on 14 d BW, but the 50% dietary CC inclusion increased BW from 28 d of age ($P < 0.01$). The birds in the WN treatment group had greater 1 to 14 d feed intake ($P < 0.01$) than those in the NL and RL treatment groups, but no differences in feed intake were observed among three floor type treatments after 14 d of age. NL and RL broilers had heavier BW than WN broilers at 28 d of age. NL birds had greater 35 d BW than WN birds ($P < 0.01$), but not the RL birds. There was no difference among the three floor type treatments after 35 d of age. Lott et al. (1992) and Amerah et al. (2008) reported that CC inclusion decreased feed intake and BW. Corzo et al. (2011) and Lilly et al. (2011) concluded that the reduced feed intake of feed containing CC was related to a limited ability to fully utilize the CC by young birds and poorer pellet quality induced by CC inclusion. As compared to previous studies, in which 50% dietary CC decreased feed intake and BW at 14 d of age (Chapter 3), 20% dietary CC did not influence 1 to 14 d feed intake.

So broilers may not be able to fully utilize much more than 20% dietary inclusion of CC at early age. During the subsequent growing and finishing periods, inclusion of 50% CC in whole pellets decreased feed intake and BW at 28, and 35 d of age (*P* < 0.01), which was associated with increased fines. Similar observations about the impaired pellet quality effect of CC inclusion in pelleted feed on feed intake and BW were made in a previous study (Chapter 3). Hu et al. (2012) reported that birds fed 100% pellets had greater feed intake and BW than birds fed 50% pellets. Mckinney et al. (2004) observed that as the proportion of pellets in the feed increased, birds consumed feed less frequently and rested more frequently. Thus, less energy was expended by feeding behavior. The increased 1 to 42 d and 1 to 42 d feed intake help explain the 150 g advantage in BW and improved FCR observed at 35 d of age. Greater feed wastage was observed from 1 to 14 d for birds raised on WN in comparison to the other litter treatments, which could explain the higher FI. The absence of floor type effects after 14 d of age was in agreement with other studies, where litter condition did not affect feed intake and BW (De Avila et al., 2008; Toghyani et al., 2010; Chapters 4 and 5).

The effects of dietary CC inclusion and floor type on AdjFCR and mortality of broilers to 49 d of age are shown in Table 6-4. No diet × litter type interaction effects were observed. Dietary inclusion of 20% CC in the starter diet did not influence the 1 to 14 d AdjFCR, but dietary inclusion of 50% CC consistently improved AdjFCR after 14 d of age (*P* < 0.01). NL and RL improved AdjFCR at 14, 28, and 35 d of age as compared to the WN treatment, but there was no difference between NL and RL. By 42 d of age, only the NL treatment group was observed to have better cumulative 42 d AdjFCR than WN (*P* < 0.01). By 49 d of age, NL had better cumulative AdjFCR than RL and WN treatments ($P < 0.01$). The NL and RL group had lower 1 to 49 d mortality rates than the WN group ($P < 0.05$). The improved AdjFCR by dietary CC inclusion was consistent with previous investigations. Kilburn and Edwards (2001) reported medium ground corn (870 µm dgw) resulted in better FCR than FC (290 µm dgw) in the diet of broiler. Amerah (2008) reported coarse grinding improved FCR in both wheat- and corn-based diets as compared to fine grinding. The FCR improvement observed in the current study was probably related to enhanced gizzard activity caused by coarse grain inclusion and eliminated the confounding factor of pellet fines. Dietary insoluble fiber has been reported to stimulate gizzard function and improve feed efficiency in a similar manner as dietary CC inclusion (Duke, 1986; Svihus et al., 2001), but many studies have also reported that litter material or litter condition did not affect feed efficiency (De Avila et al., 2008; Toghyani et al., 2010).

The effects of dietary CC inclusion and floor type on absolute and relative gizzard and proventriculus weight, as well as gizzard:proventriculus ratio at 28 and 49 d of age are shown in Table 6-5. No diet × litter type interaction effects were observed. Dietary inclusion of 50% dietary CC significantly increased absolute and relative gizzard weight ($P < 0.01$) and gizzard:proventriculus ratio ($P < 0.05$) at 28 and 49 d of age; but, it decreased absolute and relative proventriculus weight at 49 d of age ($P < 0.01$), with numerically lower absolute and relative proventriculus weight at 28 d of age. NL increased absolute and relative gizzard weight at 28 ($P < 0.01$) and 49 d of age ($P < 0.05$) as compared to the WN treatment, and there was no difference between RL and WN at either age. The absolute proventriculus weight of 28 d and 49 d broiler raised on NL floor treatment was lower than those raised on WN ($P < 0.05$). Consequently, the gizzard:proventriculus ratio was increased by NL at 28 and 49 d of age ($P < 0.01$). Dahlke et al. (2003) and Parsons et al. (2006) reported that gizzard weight increased linearly as dietary corn particle size increased, which is a logical consequence of physical stimulation of gizzard grinding activity. The gizzard:proventriculus ratio probably reflected the unique mechanical and enzymatic digestion balance within poultry stomach system. Our previous studies demonstrated that broilers may adjusted their digestive function according to diet structure and nutrient composition.

The effects of dietary CC inclusion and litter condition on pancreas, liver weight, and duodenum, jejunum and ileum unit weight are shown in Tables 6-6 and 6-7. At 28 d of age, the dietary inclusion of 50% CC increased pancreas weight ($P < 0.01$), and WN resulted in greater pancreas weight than RL ($P < 0.05$) with NL being intermediate. At 49 d of age, the dietary inclusion of 50% CC decreased liver weight ($P < 0.05$). The only treatment effect on intestine unit weight observed was increased 14 d duodenum weight unit weight among the NL and RL birds in comparison to the WN floor raised birds ($P < 0.01$).

The reports of modification of the relative size of intestinal segments by coarse diet structure are conflicting. Amerah (2007) reported all gut components were shorter in birds fed coarsely ground grain particles as compared to those fed medially ground grain particles in a mash diet, but there were no differences found in gut length when a pelleted feed was fed. Taylor and Jones (2004) found greater duodenum length in broilers fed whole wheat (200 g/kg in pelleted diet), but no difference in duodenum weight. Gabriel et al. (2008)

reported that dietary inclusion of whole wheat increased pancreas weight by 12%, but it has not been reported that whole or coarse grain could influence liver weight.

The effects of dietary CC inclusion and litter condition on litter moisture, nitrogen, and pH are shown in Table 6-8. Fresh feces under the WN floor exhibited significantly greater moisture and nitrogen content, so only the effects of NL and RL were compared. Diet × litter type interaction effect were observed for litter moisture at 49 d ($P < 0.01$), litter nitrogen at 35 and 49 d ($P < 0.05$), and litter pH and ammonia concentration at 49 d ($P < 0.01$). Dietary inclusion of 50% dietary CC decreased 49 d litter moisture ($P < 0.05$), 35 and 49 d litter nitrogen ($P < 0.05$), and 49 d litter pH ($P < 0.05$), but this was observed be most significant among broilers raised on the RL floor treatment. Dietary inclusion of 50% CC decreased litter moisture at 35 d of age ($P < 0.05$), litter nitrogen at 35 and 49 d of age ($P < 0.05$), and litter pH at 49 d of age ($P < 0.05$). The RL floor treatment had increased litter nitrogen ($P < 0.05$) at 14, 35, and 49 d of age, and litter moisture ($P < 0.05$), litter pH ($P < 0.01$) and ammonia concentration ($P < 0.01$) at 49 d of age. The decreased litter moisture and ammonia concentration due to dietary inclusion of CC has not been reported by other researchers, but Rezaei et al. (2011) reported a dose dependent decrease in litter moisture due to dietary insoluble fiber inclusion. Because the birds exhibited the same feed intake among treatments, the reduced litter nitrogen was interpreted to be associated with improved nitrogen utilization. Similarly, Parsons et al. (2006) reported dietary CC inclusion improved the efficiency of dietary nitrogen and lysine retention. The influence of dietary CC inclusion on litter pH requires further investigation due to the inconsistent results observed.

The effects of litter type and dietary CC inclusion on gizzard content weight and moisture at 28 and 49 d of age are shown in Table 6-9. No diet ×litter type interaction effects were observed. Dietary inclusion of 50% CC increased gizzard content weight ($P < 0.01$) at 28 d, and decreased gizzard content moisture at 28 and 49 d ($P < 0.01$). Floor type effects were only observed on gizzard content weight at 28 d, where NL increased content weight in comparison to WN ($P < 0.01$), but there was no difference between NL and RL. The greater digesta content observed in the gizzard of the birds fed coarse particles may have stimulated an increase in the size of the gizzard. The lower moisture of gizzard contents has not been reported in the literature. With the enhanced gizzard function, birds fed CC apparently have a more clearly compartmentalized GIT that may have altered water consumption or water absorption retention efficiency.

The effects of dietary CC inclusion and floor type on apparent ileal digestibility (AID) of energy and nitrogen are shown in Table 6-10. Dietary inclusion of 50% dietary CC improved apparent ileal digestibility (AID) of nitrogen ($P < 0.05$). A number of studies have shown improved nutrient utilization in birds when structural material is included in their diet (Preston et al., 2000; Svihus and Hetland, 2001; Rougiere et al., 2009). The improved digestibility of nutrients may have arisen from the influence of CC on decreased digesta pH, greater GIT retention time, or different intestinal morphology. It has been reported that coarse particles may slow the passage rate of digesta through the gizzard (Nir et al., 1994), increasing the exposure time of nutrients to digestive enzymes, which in turn improved nutrient digestibility (Carre, 2000). Furthermore, it has been reported that a lower pH of gizzard contents may have increased pepsin activity (Gabriel et al., 2003) and improved protein digestion.

The effects of dietary coarse corn inclusion (CC) and floor type on gizzard, proventriculus, duodenum, jejunum, ileum, and colon pH through to 49 d of age are shown in Tables 6-11 and 6-12. WN increased gizzard pH at 14 d of age if compared with NL and RL, and increased proventriculus pH at 35 d of age if compared with RL. There was no consistent influence of dietary CC inclusion or floor type on intestinal digesta pH. It has been reported that structural material, such as coarse grain or fiber, decreased the pH of gizzard contents by a magnitude of between 0.2 and 1.2 units (Dahlke et al., 2003; Gabriel et al., 2003; Engberg et al., 2004; Senkoylu et al., 2009).

The effects of dietary CC inclusion and floor type on intestinal morphology are shown in Tables 6-13 and 6-14, and Figure 6-4. Interaction effects between CC inclusion and floor type were observed for ileum muscularis depth ($P < 0.01$) and villi surface area ($P < 0.05$). Dietary inclusion of 50% CC decreased ileal muscularis thickness ($P < 0.05$) and increased ileal villi surface area ($P < 0.01$), while NL and RL increased ileal muscularis thickness ($P < 0.01$) and decreased ileal villi surface area as compared to WN ($P < 0.05$). The dietary inclusion of 50% CC increased jejunum villi height ($P < 0.01$), surface area ($P < 0.05$), V/C ratio ($P < 0.05$), and ileal villi surface area ($P < 0.05$), but decreased ileal muscularis thickness ($P < 0.05$). NL increased jejunum villi height ($P < 0.05$), surface area ($P < 0.05$), and ileal muscularis thickness ($P < 0.05$), but decreased ileal villi surface area ($P < 0.05$) as compared to WN. There have been limited and inconsistent reports on the influence of coarsely ground grain on broiler intestine morphology. Gabriel et al. (2008) reported that whole wheat increased duodenum villus, crypt length, and surface ratios at 23 d. Nir et al. (1994, 1995) reported duodenum villus height increased linearly as particle size increased. However, Amerah et al. (2007, 2008) reported that villus height, crypt depth, and epithelial thickness in the duodenum were unaffected ($P > 0.05$) by corn particle size. Dahlke et al. (2003) reported that pelleted diets resulted in a higher number of duodenal villi than mash diets, but there was no influence of corn particle size on this variable. Liu et al. (2006) reported dietary inclusion of CC decreased the number of mast cells in the deodenum, jejunum, and ileum in comparison to finely corn diets. Sarikhan et al. (2010) and Rezaei et al. (2011) observed that the inclusion of 2.5 to 7.5 g fiber/kg diet of an insoluble fiber (mostly cellulose), with a mean particle size of less than 250 μm, increased villus height:crypt depth ratio in the ileum of 42-d-old broilers. Tossaporn (2013) reported that dietary inclusion of rice hulls increased muscularis thickness of duodenum, jejunum, and ileum. Nutrients being absorbed *via* the villus surface area, results in greater nutrient absorption as villus surface area increase. Thus, as observed in our study, the improved nutrient digestibility may be due to greater villus surface area by dietary CC inclusion and litter fiber availability. The influence of dietary structural material on intestinal morphology may be due to the greater digesta retention time, which enhanced nutrient availability and facilitated greater contact between nutrient and intestinal villi, and stimulated or altered intestinal morphology.

In conclusion, birds fed pelleted and screened diets that contained 50% CC exhibited improved feed efficiency and AID of nitrogen, which may have been due to modified GIT function, as evidenced by enhanced gizzard development, and modified intestinal morphology.

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Table 6-1. Ingredient composition and calculated analysis for broiler starter, grower, and finisher diets

Item	Starter	Grower	Finisher
Ingredient		(%)	
Corn	53.65	56.34	63.91
Soybean meal, 48% CP	37.03	27.87	19.82
Dried distillers grains with solubles	5.00	10.00	10.00
Limestone	0.93	1.04	0.95
Dicalcium phosphate, 18% P	1.62	1.57	1.38
DL-Methionine	0.19	0.13	0.10
L-Lysine	0.04	0.13	0.21
L-Threonine	----	----	0.02
Sodium chloride	0.44	0.42	0.43
Vitamin premix[1]	0.05	0.05	0.05
Choline chloride (60%)	0.20	0.20	0.20
Trace mineral premix[2]	0.20	0.20	0.20
Selenium premix[3]	0.10	0.10	0.10
Coccidiostat[4]	0.05	0.05	0.05
Poultry fat	0.50	1.90	2.58
Total	100.00	100.00	100.00
Calculated analysis			
ME, kcal/g	2.95	3.05	3.15
Protein, %	23.18	20.30	17.00
Calcium, %	0.90	0.90	0.80
Available phosphorus, %	0.45	0.45	0.40
Total lysine, %	1.30	1.14	0.97
Total methionine + cysteine, %	0.95	0.83	0.71

[1] The vitamin premix supplied the following per kg feed: vitamin A, 6601; cholecalciferol, 1980 IU; niacin, 55 mg; α-tocopheral, 33 mg; pantothenic acid 11 mg; riboflavin, 6.6 mg; pyridoxine, 4 mg; menadione, 2 mg; thiamin, 2 mg; folic acid, 1.1 mg; biotin, 0.13 mg; and vitamin B12, 0.02 mg.

[2] The mineral premix supplied the following per kg of feed: Zn, 120 mg; Mn, 120 mg; Fe, 80 mg; Cu, 10 mg; I, 2.5 mg; Co, 1.0 mg.

[3] Selenium premix provided 0.2 ppm Se.

[4] Monensin was included at 99 mg/kg. (Coban 90, Elanco Animal Health, Indianapolis IN, USA).

Table 6-2. The electrical consumption during grinding by hammermill and roller mill

	Hammermill	Roller Mill	
		Top pair	Bottom pair
Grinding Setting	Two 2.4 mm screen	35% open	25% open
Grinding Time (mins)	4	4	
Horse Power (HP)	60	15	15
Horse Power (kw/h)	45	11.25	11.25
Motor Load (%)	54.62	54.38	50.51
Electricity (kw/h)	24.58	6.12	5.68
Production Rate (t/h)	0.27	0.22	
Electricity (kw/t)	91.04	27.82	25.82
Electricity (kw/t/h)	6.07	1.85	1.72
Total Electricity (kw/t/h)	6.07	3.57	
Electricity Price (cents/kw/h)	11.3	11.3	
Grinding Cost (cents/ton feed)	41.15[1]	20.58+11.1=31.68[2]	
Feed Cost Difference (cents/ton)	9.47		

1 HP=0.75 kw/h

Electricity (kw/h) =Horse power*0.75*(Motor load/100)

Electricity (kw/t) =Electricity (kw/h)/Production Rate (t/h)

Electricity (kw/t/h) =Electricity (kw/t) / (4 min/60 min/h)

Total Electricity (kw/t/h) of Roller mill =Top pair + Bottom pair

Electricity Price: Based on NC local market price provided by Duke Energy Carolinas 2013

[1] Grinding cost= Electricity (kw/t) * Unit price (cents/kw)*60%

[2] Grinding cost=30% feed ground by hammermill +30% feed ground by roller mill= Electricity by hammermill (kw/t) * Unit price (cents/kw)*30% + Electricity by roller mill (kw/t) * Unit price (cents/kw)*60%

In the formula there was about 60% corn in grower and finisher diet, and 50% CC inclusion means 30% corn ground by hammermill and 30% corn ground by roller mill, such 1 ton feed contained 600 kg total corn of which 300 kg was ground by hammermill and 300 kg ground by roller mill.

Table 6-3. Effects of dietary coarse corn (CC) and floor type on feed intake and BW of broilers from 0 to 49 d of age

CC[1]	Floor type[1]	n	Feed Intake					BW				
			14 d	28 d	35 d	42 d	49 d	14 d	28 d	35 d	42 d	49 d
Interaction Effects[1]							(g)					
0%	WN	6	658	2565	3720	5481	7157	530	1698	2230	3045	3747
50%	WN	6	647	2622	3860	5724	7426	528	1793	2399	3231	3898
0%	NL	6	630	2587	3776	5600	7139	532	1780	2357	3167	3823
50%	NL	6	616	2571	3780	5554	7170	523	1802	2451	3266	3930
0%	RL	6	638	2575	3719	5408	6924	537	1760	2260	3027	3625
50%	RL	6	629	2615	3828	5614	7259	530	1813	2462	3272	3968
SEM			7.2	24.2	56.0	71.8	96.9	4.0	16.6	26.4	39.8	52.9
Main Effects												
0%		12	642	2575	3738	5496^{b}	7073^{b}	533	1745^{B}	2283^{B}	3080^{B}	3732^{B}
50%		12	631	2603	3823	5631^{a}	7285^{a}	527	1802^{A}	2437^{A}	3256^{A}	3932^{A}
SEM			4.2	14.0	32.3	41.4	56.0	2.3	9.6	16.2	24.4	32.5
	WN	18	653^{A}	2594	3790	5603	7292	529	1745^{b}	2315^{B}	3138	3823
	NL	18	623^{B}	2579	3778	5577	7155	527	1791^{a}	2404^{A}	3216	3876
	RL	18	634^{B}	2595	3774	5511	7091	533	1787^{a}	2361^{AB}	3150	3796
	SEM		5.1	17.1	39.6	50.8	68.5	2.8	11.7	19.6	29.5	39.2
Source of Variation							*P-value*					
CC * Floor type			0.92	0.31	0.47	0.11	0.27	0.68	0.11	0.15	0.23	0.09
CC			0.07	0.18	0.08	0.03	0.01	0.06	< 0.01	< 0.01	< 0.01	< 0.01
Litter Type			< 0.01	0.77	0.96	0.44	0.14	0.32	0.02	< 0.01	0.14	0.35

$^{a, b}$ Means within a column with different superscripts differ significantly ($P \leq 0.05$).

$^{A, B}$ Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of wire net (WN), new wood shavings litter (NL) or recycled old litter (RL), and 0 or 20% CC inclusion in starter diets followed by 50% CC inclusion in grower and finisher diets.

Table 6-4. Effects of dietary coarse corn (CC) and floor type on adjusted feed conversion ratio (AdjFCR) and mortality of broilers from 1 to 49 d of age

CC[1]	Floor type[1]	n	AdjFCR					Mortality
			14 d	28 d	35 d	42 d	49 d	49 d
Interaction Effects[1]					(g feed/g BW gain)			(%)
0%	WN	6	1.35	1.57	1.77	1.93	2.09	0.07
50%	WN	6	1.34	1.52	1.68	1.88	2.06	0.05
0%	NL	6	1.28	1.50	1.69	1.89	2.04	0.01
50%	NL	6	1.28	1.47	1.63	1.83	2.01	0.03
0%	RL	6	1.29	1.51	1.72	1.92	2.08	0.02
50%	RL	6	1.29	1.49	1.65	1.86	2.04	0.02
SEM			0.01	0.01	0.01	0.01	0.01	0.01
Main Effects								
0%		12	1.31	1.53^{A}	1.73^{A}	1.91^{A}	2.07^{A}	0.03
50%		12	1.30	1.49^{B}	1.65^{B}	1.86^{B}	2.04^{B}	0.03
SEM			0.01	0.01	0.01	0.01	0.01	0.02
	WN	18	1.34^{A}	1.54^{A}	1.72^{A}	1.90^{a}	2.08^{A}	0.06^{a}
	NL	18	1.28^{B}	1.49^{B}	1.66^{B}	1.86^{b}	2.02^{B}	0.02^{b}
	RL	18	1.29^{B}	1.50^{B}	1.69^{B}	1.89^{ab}	2.06^{A}	0.02^{b}
	SEM		0.01	0.01	0.01	0.01	0.01	0.01
Source of Variation					*P-value*			
CC * Floor type			0.82	0.16	0.26	0.99	0.99	0.34
CC			0.54	< 0.01	< 0.01	< 0.01	< 0.01	0.93
Floor type			< 0.01	< 0.01	< 0.01	0.02	< 0.01	0.03

[a, b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

[A, B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of wire net (WN), new wood shavings litter (NL) or recycled old litter (RL), and 0 or 20% CC inclusion in starter diets followed by 50% CC inclusion in grower and finisher diets.

Table 6-5. Effects of dietary coarse corn (CC) and floor type on absolute and relative weight of gizzard and proventriculus, and gizzard: proventriculus ratio (G/P) of broilers at 28 and 49 d age

CC[1]	Floor type[1]	n	Gizzard				Proventriculus				G/P	
			28 d		49 d		28 d		49 d		28 d	49 d
Interaction Effects[1]			(g)	(mg/g)	(g)	(mg/g)	(g)	(mg/g)	(g)	(mg/g)		(g/g)
0%	WN	6	15.9	8.8	25.0	6.4	9.7	5.4	11.9	3.1	1.7	2.15
50%	WN	6	19.9	10.8	28.0	7.5	10.7	5.9	8.7	2.3	2.0	3.34
0%	NL	6	18.3	11.1	25.9	6.8	8.3	5.0	9.3	2.4	2.3	2.81
50%	NL	6	23.6	12.7	33.1	8.6	7.7	4.1	8.4	2.2	3.1	2.99
0%	RL	6	17.9	10.5	24.3	6.7	9.3	5.3	9.8	2.7	2.2	2.52
50%	RL	6	21.7	12.6	29.0	7.6	7.1	4.1	8.8	2.3	3.1	3.38
SEM			1.0	0.7	1.1	0.2	1.1	0.6	0.6	0.1	0.2	0.2
Main Effects												
0%		12	17.4^{B}	10.2^{B}	25.1^{B}	6.6^{B}	9.1	5.2	10.3^{A}	2.7^{A}	2.1^{B}	2.49^{B}
50%		12	21.7^{A}	12.0^{A}	30.2^{A}	7.9^{A}	8.5	4.7	8.6^{B}	2.3^{B}	2.7^{A}	3.57^{A}
SEM			0.6	0.4	0.6	0.1	0.6	0.3	0.3	0.1	0.1	0.1
	WN	18	17.9^{b}	9.6^{B}	26.7^{b}	7.0^{B}	10.2	5.6	10.3^{a}	2.7^{a}	1.8^{B}	2.74^{B}
	NL	18	21.0^{a}	11.9^{A}	29.5^{a}	7.7^{A}	8.0	4.6	8.8^{b}	2.3^{b}	2.7^{A}	3.40^{A}
	RL	18	19.8^{ab}	11.6^{AB}	26.7^{b}	7.1^{B}	8.2	4.7	9.3^{ab}	2.5^{ab}	2.6^{A}	2.95^{AB}
	SEM		0.8	0.5	0.8	0.2	0.7	0.4	0.4	0.10	0.2	0.2
Source of Variation			*P-value*									
CC * Floor type			0.76	0.93	0.23	0.15	0.29	0.28	0.08	0.15	0.36	0.7
CC			< 0.01	< 0.01	< 0.01	< 0.01	0.50	0.24	< 0.01	< 0.01	< 0.01	< 0.01
Floor type			0.02	0.01	0.02	0.01	0.07	0.12	0.04	0.03	< 0.01	0.01

[a, b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

[A, B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of wire net (WN), new wood shavings litter (NL) or recycled old litter (RL), and 0 or 20% CC inclusion in starter diets followed by 50% CC inclusion in grower and finisher diets.

Table 6-6. Effect of dietary coarse corn (CC) and floor type on pancreas and liver weight from 1 to 49 d of age

CC[1]	Floor type[1]	n	Pancreas 14 d	Pancreas 28 d	Pancreas 35 d	Pancreas 42 d	Pancreas 49 d	Liver 14 d	Liver 35 d	Liver 49 d
Interaction Effects[1]							(g)			
0%	WN	6	2.0	3.9	4.4	6.1	5.4	18.1	56.5	82.3
50%	WN	6	2.0	4.6	4.1	5.2	5.2	19.2	60.1	79.4
0%	NL	6	1.8	3.6	4.0	5.4	5.3	19.0	62.7	83.1
50%	NL	6	2.0	4.1	4.2	5.2	5.2	18.2	61.9	71.2
0%	RL	6	2.0	3.2	4.0	4.8	5.6	19.2	62.3	80.1
50%	RL	6	2.0	4.0	3.8	4.6	5.7	17.9	66.0	74.6
SEM			0.1	0.2	0.2	0.4	0.2	0.9	3.3	3.0
Main Effects										
0%		12	1.9	3.5^{B}	4.1	5.4	5.4	18.8	60.5	85.8^{a}
50%		12	2.0	4.2^{A}	4.1	5.0	5.4	18.5	62.7	75.1^{b}
SEM			0.1	0.1	0.1	0.2	0.1	0.5	1.9	1.7
	WN	18	2.0	4.2^{a}	4.3	5.6	5.3	18.7	58.3	80.9
	NL	18	1.9	3.8^{ab}	4.1	5.3	5.3	18.6	62.3	77.1
	RL	18	2.0	3.6^{b}	3.9	4.7	5.6	18.5	64.2	77.3
	SEM		0.1	0.2	0.2	0.3	0.1	0.7	2.3	2.1
Source of Variation							*P-value*			
CC * Floor type			0.75	0.76	0.51	0.62	0.77	0.42	0.75	0.32
CC			0.63	< 0.01	0.61	0.22	0.70	0.69	0.44	0.01
Floor type			0.66	< 0.05	0.25	0.11	0.14	0.99	0.22	0.39

[a, b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

[A, B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of wire net (WN), new wood shavings litter (NL) or recycled old litter (RL), and 0 or 20% CC inclusion in starter diets followed by 50% CC inclusion in grower and finisher diets.

Table 6-7. Effect of dietary coarse corn (CC) and floor type on duodenum, jejunum and ileum unit weight (g/cm) at 14 and 35 d of age

CC[1]	Floor type[1]	n	Duodenum		Jejunum		Ileum	
			14 d	35 d	14 d	35 d	14 d	35 d
Interaction Effects[1]					(g/cm)			
0%	WN	6	1.30	2.3	0.88	1.8	0.56	1.2
50%	WN	6	1.15	2.2	0.89	1.9	0.61	1.2
0%	NL	6	1.00	2.2	0.94	1.7	0.64	1.3
50%	NL	6	1.05	2.4	0.76	1.8	0.62	1.2
0%	RL	6	1.22	2.4	0.92	1.6	0.61	1.2
50%	RL	6	1.32	2.2	1.03	1.6	0.69	1.0
SEM			0.07	0.1	0.06	0.1	003	0.1
Main Effects								
0%		12	1.17	2.29	0.91	1.7	0.61	1.22
50%		12	1.17	2.25	0.89	1.8	0.64	1.12
SEM								
	WN	18	1.03^{B}	2.3	0.85	1.7	0.63	1.2
	NL	18	1.22^{A}	2.2	0.88	1.8	0.59	1.2
	RL	18	1.27^{A}	2.3	0.97	1.6	0.65	1.1
	SEM		0.05	0.1	0.05	0.1	0.02	0.05
Source of Variation					*P-value*			
CC * Floor type			0.18	0.15	0.09	0.97	0.24	0.23
CC			0.99	0.72	0.72	0.59	0.16	0.10
Floor type			< 0.01	0.88	0.14	0.18	0.14	0.08

[a, b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

[A, B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of wire net (WN), new wood shavings litter (NL) or recycled old litter (RL), and 0 or 20% CC inclusion in starter diets followed by 50% CC inclusion in grower and finisher diets.

Table 6-8. Effects of dietary coarse corn (CC) and floor type on litter moisture, nitrogen, pH, and ammonia emission from 0 to 49 d of age

CC	Litter	n	Moisture						Nitrogen			pH	Ammonia
			14 d	21 d	28 d	35 d	42 d	49 d	14 d	35 d	49 d	49 d	49 d
Interaction Effects [1]						(%)							(ppm)
0%	NL	6	26.0	38.4	40.9	40.1	33.8	34.9^{b}	3.9	6.1^{b}	6.1^{b}	8.19^{A}	36.5^{C}
50%	NL	6	27.2	34.8	42.8	37.7	29.2	33.1^{b}	4.1	5.9^{b}	5.2^{b}	7.72^{B}	38.8^{BC}
0%	RL	6	27.0	35.0	44.0	45.0	36.7	40.6^{a}	4.7	7.2^{a}	6.9^{a}	8.40^{A}	52.3^{A}
50%	RL	6	27.9	34.3	40.2	36.8	29.9	35.3^{b}	4.9	5.8^{b}	5.8^{b}	8.11^{A}	43.7^{B}
SEM			0.3	0.6	0.5	0.4	0.4	0.4	0.1	0.1	0.1	0.15	2.4
Main Effects													
0%		12	26.5	36.7	42.4	42.6^{a}	35.3^{a}	37.8^{a}	4.3	6.6^{a}	6.5^{a}	7.83^{a}	44.6
50%		12	27.6	34.6	41.5	37.3^{b}	29.5^{b}	34.2^{b}	4.5	5.9^{b}	5.5^{b}	7.47^{b}	41.2
SEM			0.2	0.4	0.3	0.3	0.3	0.2	0.1	0.1	0.1	0.11	1.8
	NL	12	26.6	36.6	41.9	38.9	31.5	34.0^{B}	4.0^{B}	6.0^{b}	5.6^{b}	7.96^{B}	37.6^{B}
	RL	12	27.5	34.6	42.1	40.9	33.3	38.0^{A}	4.8^{A}	6.5^{a}	6.3^{a}	8.26^{A}	48.2^{A}
	SEM		0.2	0.4	0.3	0.3	0.3	0.2	0.1	0.1	0.1	0.11	1.8
Source of variation							P-value						
CC * Litter			0.33	0.14	0.12	0.62	0.65	0.38	0.25	0.02	0.02	< 0.01	< 0.01
CC			0.61	0.12	0.43	0.04	0.02	0.04	0.31	0.04	0.03	0.04	0.06
Litter Form			0.33	0.12	0.87	0.21	0.09	0.01	< 0.01	0.04	0.03	< 0.01	< 0.01

$^{a, b, c}$ Means within a column with different superscripts differ significantly ($P \leq 0.05$).

$^{A, B, C}$ Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of wire net (WN), new wood shavings litter (NL) or recycled old litter (RL), and 0 or 20% CC inclusion in starter diets followed by 50% CC inclusion in grower and finisher diets.

Table 6-9. Effects of dietary coarse corn (CC) and floor type on gizzard content weight and moisture at 28 and 49 d of age

CC	Litter	n	Gizzard Content Weight		Gizzard Content Moisture	
			28 d	49 d	28 d	49 d
Interaction Effects [1]			(g)		(%)	
0%	WN	6	4.6	29.6	0.76	0.80
50%	WN	6	18.1	41.5	0.67	0.65
0%	NL	6	14.9	30.4	0.72	0.75
50%	NL	6	26.4	32.9	0.66	0.68
0%	RL	6	12.8	24.3	0.74	0.75
50%	RL	6	20.0	30.3	0.67	0.68
SEM			3.0	6.4	0.02	0.02
Main Effects						
0%		18	10.8^{B}	28.1	0.74^{A}	0.77^{A}
50%		18	21.5^{A}	34.9	0.66^{B}	0.69^{B}
SEM			1.6	3.7	0.01	0.01
	WN	12	11.3^{B}	35.6	0.71	0.73
	NL	12	20.6^{A}	31.6	0.69	0.71
	RL	12	16.4^{AB}	27.3	0.70	0.71
	SEM		2.0	4.5	0.02	0.01
Source of variation			*P-value*			
CC * Litter			0.52	0.76	0.80	0.09
CC			< 0.01	0.20	< 0.01	< 0.01
Litter Form			0.01	0.44	0.41	0.81

[a, b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

[A, B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of wire net (WN), new wood shavings litter (NL) or recycled old litter (RL), and 0 or 20% CC inclusion in starter diets followed by 50% CC inclusion in grower and finisher diets.

Table 6-10. Effects of dietary coarse corn (CC) and floor type on broilers apparent ileal digestibility of nitrogen and energy at 49 d of age

CC[1]	Floor type[1]	n	Nitrogen	Energy
Interaction Effects[1]			(% digestibility)	
0%	WN	6	66.8	64.9
50%	WN	6	69.9	69.6
0%	NL	6	64.6	64.1
50%	NL	6	69.7	69.6
0%	RL	6	65.1	65.7
50%	RL	6	69.1	67.0
SEM			1.4	1.7
Main Effects				
0%		18	65.5[b]	64.9
50%		18	69.6[a]	68.7
SEM			0.4	0.7
	WN	12	68.4	67.8
	NL	12	67.3	66.9
	RL	12	67.2	66.9
	SEM		0.3	0.4
Source of Variation			*P-value*	
CC * Floor type			0.65	0.29
CC			0.03	0.15
Floor type			0.17	0.38

[a, b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

[A, B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of wire net (WN), new wood shavings litter (NL) or recycled old litter (RL), and 0 or 20% CC inclusion in starter diets followed by 50% CC inclusion in grower and finisher diets.

Table 6-11. Effects of dietary coarse corn (CC) and floor type on gizzard and proventriculus pH from 14 to 49 d of age

CC[1]	Floor type[1]	n	Gizzard					Proventriculus			
			14 d	28 d	35 d	42 d	49 d	28 d	35 d	42 d	49 d
Interaction Effects[1]							(pH)				
0%	WN	6	3.2	3.5	3.3^{AB}	4.4	3.7	3.3	3.7	4.2	5.1
50%	WN	6	3.1	2.9	3.3^{AB}	3.7	3.6	3.1	3.8	4.4	4.7
0%	NL	6	2.7	3.2	3.5^{A}	4.2	4.0	3.2	3.5	4.1	5.1
50%	NL	6	2.7	3.0	2.8^{B}	3.7	3.5	3.1	3.7	3.7	5.0
0%	RL	6	2.8	4.1	2.8^{B}	3.7	3.7	3.7	2.9	3.7	4.6
50%	RL	6	2.8	3.3	3.3^{AB}	3.7	4.0	2.9	3.3	4.0	5.2
SEM			0.2	0.3	0.2	0.5	0.2	0.3	0.2	0.4	0.4
Main Effects											
0%		12	2.9	3.6	3.2	4.1	3.8	3.4	3.4	4.0	4.9
50%		12	2.9	3.0	3.1	3.7	3.7	3.0	3.6	4.1	5.0
SEM			0.1	0.2	0.1	0.3	0.2	0.1	0.1	0.3	0.3
	WN	18	3.2^{A}	3.2	3.3	4.1	3.6	3.2	3.8^{a}	4.3	4.9
	NL	18	2.7^{B}	3.1	3.1	4.0	3.7	3.1	3.6^{ab}	3.9	5.0
	RL	18	2.8^{B}	3.7	3.0	3.7	3.8	3.3	3.1^{b}	3.8	4.9
SEM			0.1	0.3	0.1	0.3	0.2	0.2	0.2	0.3	0.3
Source of Variation							*P-value*				
CC * Floor type			0.88	0.71	< 0.01	0.76	0.36	0.23	0.89	0.72	0.46
CC			0.90	0.06	0.79	0.31	0.81	0.08	0.23	0.88	0.91
Floor type			< 0.01	0.21	0.38	0.75	0.75	0.78	0.03	0.47	0.92

$^{a, b}$ Means within a column with different superscripts differ significantly ($P \leq 0.05$).

$^{A, B}$ Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of wire net (WN), new wood shavings litter (NL) or recycled old litter (RL), and 0 or 20% CC inclusion in starter diets followed by 50% CC inclusion in grower and finisher diets.

Table 6-12. Effects of dietary coarse corn (CC) and floor type on duodenum, jejunum, ileum, and colon pH at 14 and 35 d of age

CC[1]	Floor type[1]	n	Duodenum		Jejunum		Ileum		Colon	
			14 d	35 d	14 d	35 d	14 d	35 d	14 d	35 d
Interaction Effects[1]						(pH)				
0%	WN	6	6.3^{b}	6.1	6.1	5.7	6.1	5.9	6.7	7.1
50%	WN	6	6.3^{b}	6.4	6.1	5.8	6.0	5.9	6.4	6.8
0%	NL	6	6.2^{b}	6.3	6.2	5.9	5.8	6.3	6.3	7.0
50%	NL	6	6.2^{b}	6.4	6.1	5.9	6.1	6.2	6.4	6.8
0%	RL	6	6.6^{a}	6.2	6.0	5.7	6.0	5.7	6.6	6.4
50%	RL	6	6.1^{b}	6.7	6.0	6.1	5.9	6.0	6.4	6.9
SEM			0.1	0.2	0.1	0.1	0.1	0.14	0.2	0.2
Main Effects										
0%		12	6.4^{a}	6.2	6.1	5.8	6.0	6.0	6.5	6.9
50%		12	6.2^{b}	6.5	6.1	5.9	6.0	6.0	6.4	6.9
SEM			0.1	0.1	0.1	0.1	0.04	0.1	0.1	0.1
	WN	18	6.3	6.2	6.1	5.8	6.0	6.0^{AB}	6.6	7.0
	NL	18	6.2	6.4	6.1	5.9	6.0	6.3^{A}	6.4	6.9
	RL	18	6.3	6.4	6.0	5.9	5.92	5.8^{B}	6.5	6.7
			0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	SEM									
Source of Variation						P-value				
CC * Floor type			0.03	0.67	0.88	0.26	0.02	0.27	0.63	0.07
CC			0.03	0.07	0.76	0.11	0.67	0.75	0.38	1
Floor type			0.37	0.58	0.46	0.50	0.32	< 0.01	0.39	0.29

[a, b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

[A, B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of wire net (WN), new wood shavings litter (NL) or recycled old litter (RL), and 0 or 20% CC inclusion in starter diets followed by 50% CC inclusion in grower and finisher diets.

Table 6-13. Effects of dietary coarse corn (CC) inclusion and floor type on broiler jejunum morphology at 49 d of age

CC^{1}	Litter^{1}	n	Tip width	Villus Height	Base width	Crypt Depth	Muscularis layer	Surface Area	V/C^{2}
Interaction Effects^{1}					(μm)			(μm^{2}×10^{-3})	
0%	WN	6	202	1574	250	236	304	356	6.68
50%	WN	6	138	1979	253	256	291	387	7.74
0%	NL	6	189	1735	267	222	277	396	7.82
50%	NL	6	179	1970	237	231	266	409	8.54
0%	RL	6	211	1419	256	223	263	331	6.35
50%	RL	6	182	2062	266	242	265	462	8.52
SEM			10.2	30.1	9.2	7.8	8.2	12.1	0.3
Main Effects									
0%		18	201	1576^{B}	258	227	281	361^{b}	6.94^{b}
50%		18	166	2004^{A}	252	243	274	419^{a}	8.25^{a}
SEM			8.2	10.2	6.3	5.6	4.3	9.3	0.3
	WN	12	170	1777^{b}	252	246	298	375^{b}	7.23
	NL	12	184	1852^{a}	252	226	271	404^{a}	8.19
	RL	12	197	1740^{b}	261	233	264	398^{a}	7.48
	SEM		7.1	6.6	3.8	4.3	2.9	6.5	0.2
Source of variation						*P-value*			
CC * Floor type			0.06	0.24	0.10	0.75	0.22	0.37	0.21
CC			0.09	< 0.01	0.49	0.21	0.18	0.04	0.02
Floor type			0.34	0.04	0.31	0.28	0.89	0.04	0.11

[a, b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

[A, B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of wire net (WN), new wood shavings litter (NL) or recycled old litter (RL), and 0 or 20% CC inclusion in starter diets followed by 50% CC inclusion in grower and finisher diets.

[2] V/C=villus height: crypt depth ratio.

Table 6-14. Effects of dietary coarse corn (CC) inclusion and floor type on broiler ileum morphology at 49 d of age

CC[1]	Litter[1]	n	Tip width	Villus Height	Base width	Crypt Depth	Muscularis layer	Surface Area	V/C[2]
Interaction Effects[1]					(µm)			($\mu m^2 \times 10^{-3}$)	
0%	WN	6	185	1337	214	200	273	266	6.69
50%	WN	6	199	1507	238	170	233	329	8.89
0%	NL	6	195	1221	225	171	326	257	7.16
50%	NL	6	175	1307	213	165	285	253	7.93
0%	RL	6	164	1229	184	156	352	214	7.86
50%	RL	6	196	1369	200	163	296	271	8.38
SEM			7.3	13.2	9.8	5.4	3.2	11.1	0.3
Main Effects									
0%		18	181	1262	208	176	317^{a}	246^{b}	7.19
50%		18	190	1395	217	166	271^{b}	284^{a}	8.40
SEM			6.1	7.2	6.1	3.1	4.0	7.8	0.3
	WN	12	192	1422	226	185	253^{B}	297^{a}	7.70
	NL	12	185	1264	219	168	305^{A}	255^{b}	7.54
	RL	12	180	1299	192	160	324^{A}	242^{b}	8.12
	SEM		4.6	5.8	3.9	2.0	3.1	5.4	0.2
Source of variation						*P-value*			
CC * Floor type			0.11	0.25	0.29	0.31	< 0.01	0.03	0.85
CC			0.14	0.07	0.33	0.67	0.03	< 0.01	0.05
Floor type			0.18	0.06	0.91	0.79	0.01	0.02	0.13

[a, b] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

[A, B] Means within a column with different superscripts differ significantly ($P \leq 0.01$).

[1] Treatments consisted of wire net (WN), new wood shavings litter (NL) or recycled old litter (RL), and 0 or 20% CC inclusion in starter diets followed by 50% CC inclusion in grower and finisher diets.

[2] V/C=villus height: crypt depth ratio.

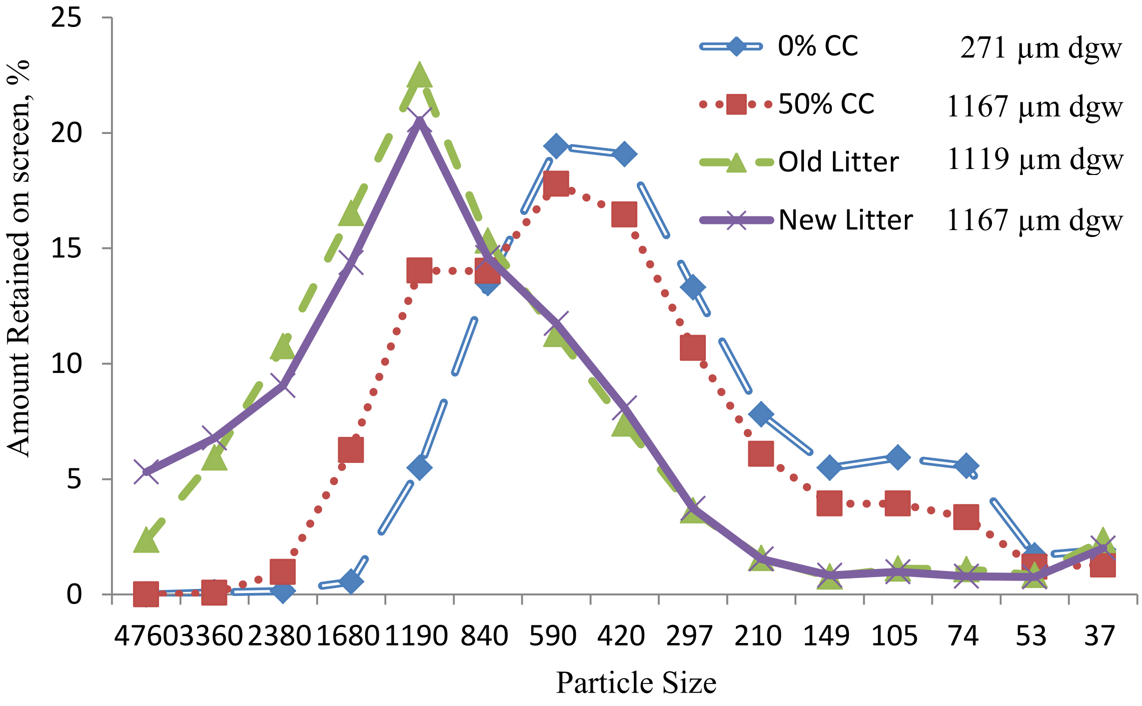

Figure 6-1. The geometric mean diameter by mass (dgw) and particle size distribution of fine corn (FC), coarse corn (CC), old litter, and new wood shavings litter

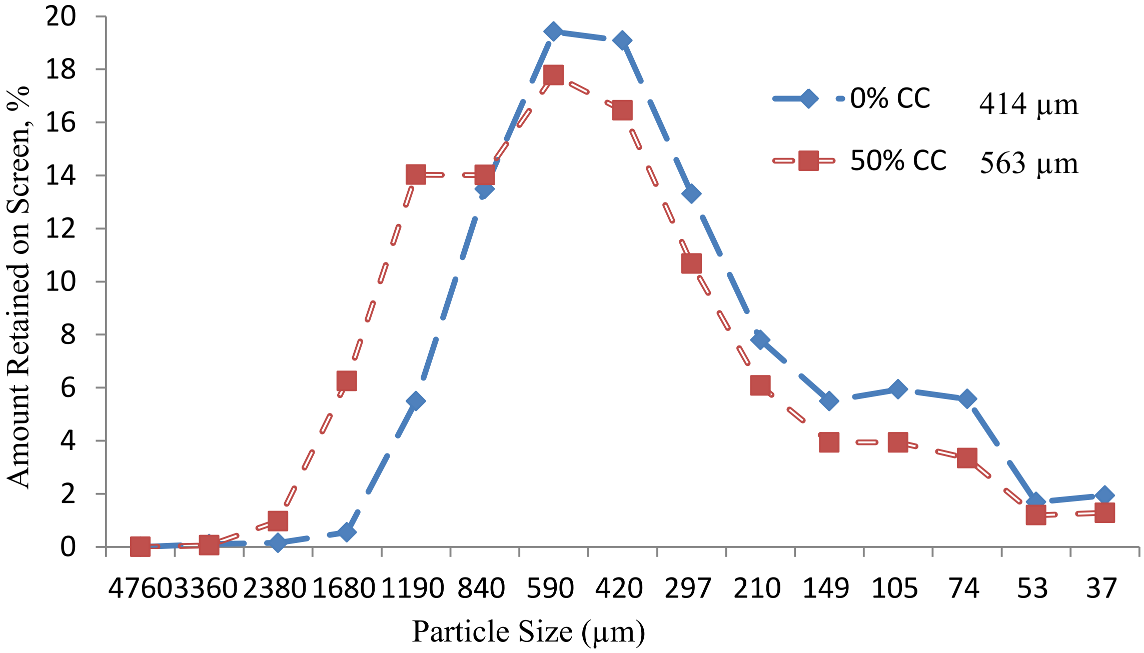

Figure 6-2. The geometric mean diameter by mass (dgw) and particle size distribution of mash grower diets prior to pelleting with 0 and 50% coarse corn (CC) replaced fine corn (FC)

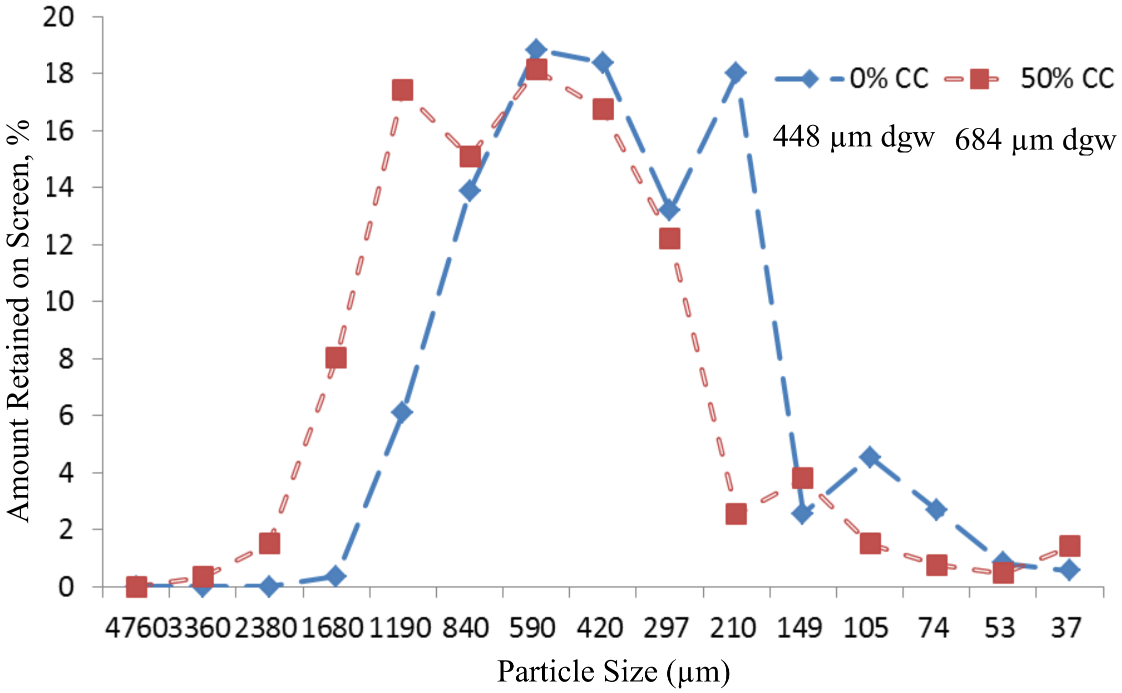

Figure 6-3. The geometric mean diameter by mass (dgw) and particle size distribution of mash finisher diets prior to pelleting with 0 and 50% coarse corn (CC) replaced fine corn (FC)

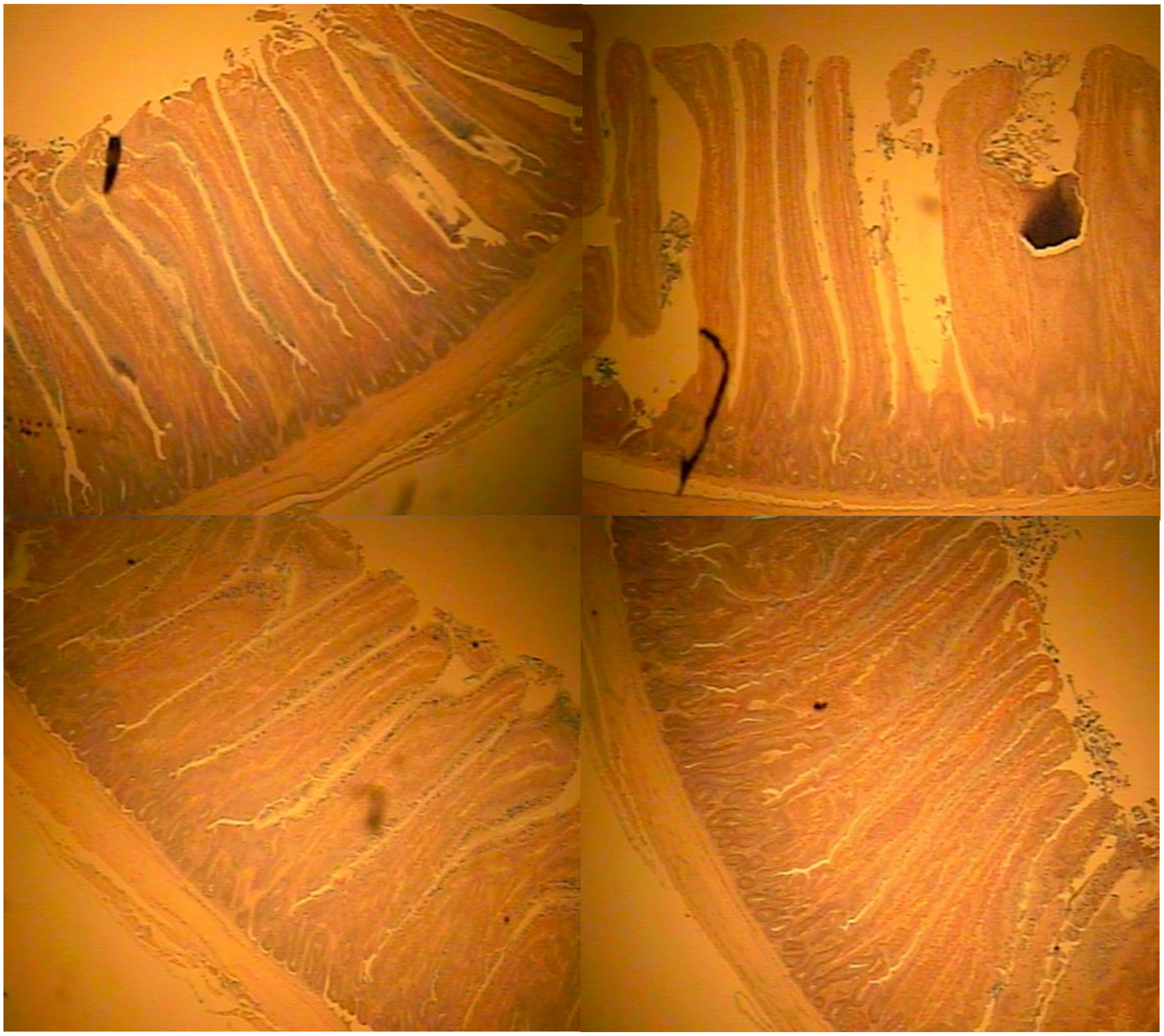

Figure 6-4. The influence of coarse corn (CC) inclusion and litter type on jejunum villus structure

Top left: Jejunum villus, 0% CC with new litter.
Top right: Jejunum villus, 0% CC with old litter.
Bottom left: Jejunum villus, 50% CC with new litter.
Bottom right: Jejunum villus, 50% CC with old litter.

CHAPTER 7

OVERALL DISCUSSION AND CONCLUSIONS

Feed costs, production efficiency, gut health, and environment sustainability are major challenges to poultry industry. Indeed, gut function is central to the resolution of those challenges. With increasing public and industry scrutiny about the use of antibiotic feed additives to management gut health, nutritionists must consider other paradigms that maintain gut health and function, and improve the utilization of dietary nutrients. As the most important interface between the external environment and the body, the gastro-intestinal tract's major role is to extract nutrients from feeds to support growth, maintenance, and reproduction. The GIT is the largest endocrine gland, which produces at least 20 hormones, regulatory peptides, and their receptors, and it is the largest part of the immune system. Based on whole wheat feeding literature and the apparent importance of dietary structure to normalize gut function, different strategies were evaluated in this dissertation research to optimize gut function and nutrient utilization efficiency. Dietary inclusion of whole wheat is a popular feeding practice in the EU, Australian and Canada, and it had been reported to reduce feed costs and increase feed milling capacity, improve growth performance and FCR, enhance flock health and decrease mortality, stimulate GIT development with better gut motility, and increase net profit of broiler production. So the general objective of this dissertation research is to obtain similar benefits by dietary inclusion of course ground corn in pelleted corn-soy diets of broilers raise on litter floors.

The general hypothesis that served as the underlying theme of this dissertation is as follows: dietary inclusion of CC stimulates gizzard motility activity, enhanced function of the gizzard and gut, influences enteric ecosystem development, and consequently improves digestion, nutrient utilization and broiler live performance. Six experiments were completed to test this hypothesis in different treatment scenarios that control some confounding factors such as feed form, genders, corn particle size and distribution, pellet quality, and litter condition.

In order to test the hypothesis that broilers respond differently to dietary CC inclusion when presented in different feed forms, the first experiment (Chapter 2) evaluated the effects inclusion levels of coarsely ground corn (CC) in mash and pellet-crumbled diets on broilers from 1 to 14 d of age. This study was a 2 × 6 factorial arrangement of two feed forms (mash and pellet-crumble) and six dietary CC inclusions (0, 10, 20, 30, 40, and 50% CC that replaced fine corn (FC)), and live performance, BW uniformity, relative gizzard weight, fecal nitrogen, and particle size preference behaviors were measured. As expected, the birds the fed pellet-crumbled diet performed better than those fed the mash diets, and dietary CC inclusion stimulated gizzard development and particle size preference behaviors. The birds exhibited a preference for larger particles at 7 d of age in both feed forms. A significant form X CC level effect revealed that particle size was more critical in a mash diet than in a crumbled diet. Because selective feeding behavior for coarse particles would create an imbalance in nutrient intake and result in poor live performance, the effect of dietary inclusion of CC was only tested in pellet diets in the subsequent studies. In addition, the linear decrease in fecal nitrogen as dietary CC inclusion increased revealed that CC may improve protein digestibility and amino acid utilization.

As litter condition and gender may confound the effect of dietary CC inclusion on broiler live performance, experiments 2 and 3 (Chapter 3) were conducted to assess the influence of these confounding factors of the dietary CC inclusion on broiler live performance. Gizzard development, litter characteristics, and colon bacterial profiles were assessed as indicators change in GIT function. Experiment 1 was a 2 × 2 factorial arrangement of 2 genders (male or female) and 2 CC levels (0 or 50%), and Experiment 2 was a 2 × 2 factorial arrangement of 2 CC levels (0 or 50%) and 2 litter types (finely ground old litter or new wood shavings litter). The gender × diet interaction effect observed on feed intake and BW gain from 14 to 35 d demonstrated male and female broilers responded differently to dietary CC inclusion. Since the male broilers had higher feed intake and BW gain, they exhibited a greater response to dietary CC inclusion so only males were used in the subsequent studies. Although dietary inclusion of CC resulted in depressed feed intake during the starter phase (1-14 d) in both experiments, increased adjusted feed conversion ratio (AdjFCR) in the subsequent grower and finisher phases indicated that pelleting quality could be a confounding factor. Dietary inclusion of CC increased relative gizzard weight and decreased relative proventriculus weight at 49 d, which implied that broilers may adjust their mechanical and enzymatic digestive function according feed structure. The colon bacterial profile was totally changed by dietary inclusion of CC, indicating that dietary structural components not only altered gut motility and physiology, but also the microbial ecosystem of the gut. In conclusion, dietary inclusion of 50% CC increased relative gizzard weight, improved AdjFCR, reduced fecal N, and altered colon bacterial profile, wherease new litter had only a marginal benefit on broiler live performance.

In order to demonstrate that the reduced feed intake by dietary CC inclusion observed in the previous studies was more likely due the confounding effect of reduced pellet quality, experiment 4 (Chapter 4) was conducted on screened grower and finisher feed pellets with fines removed. In addition, the effects of the dietary inclusion of two coarsely ground corn levels (0 or 50% CC) of broilers reared on two litter types (finely ground old litter or new wood shavings litter) was evaluated. Growth performance, litter characteristics, gastrointestinal tract (GIT) development, apparent ileal digestibility (AID) of energy and nitrogen (N), and intestinal morphology were measured in this experiment. Dietary inclusion of 50% CC in screened whole pellet feeding improved cumulative AdjFCR at 35 and 49 d of age, and improved the AID of energy and N by 6.8% and 3.5% at 49 d of age, respectively. The improved nutrient digestibility and growth performance could be partly due to the enhanced intestinal mucosa morphology, such as increased jejunum villi tip width and villi surface area. Evidently, birds fed screened pelleted diets containing 50% CC had improved AdjFCR and AID of energy and N because of enhanced GIT functional development and intestinal mucosa morphology.

Experiment 5 was a 45 d cage study investigated the effects of three dietary inclusion levels of CC on broiler live performance and apparent ileal digestibility (AID) of energy and nitrogen (Chapter 5). The gizzard, proventriculus, intestinal section development, digesta pH, retention time, and particle size distribution were measured as indicators of GIT motility, development, and functional change by dietary CC inclusion. Feed efficiency and AID of energy and nitrogen were improved by dietary CC inclusion, which may be due to the reduced digesta pH and increased digesta retention time. The digesta particles in the jejunum had a similar distribution and a dgw of 218, 204, and 181 µm with 0, 25, of 50% CC inclusion, respectively. Evidently, only a certain particle size (about 200 µm) can leave the gizzard. In conclusion, birds fed screened pelleted diets containing 25% and 50% CC exhibited increased BW, improved feed efficiency, and increased AID of energy and N, which was probably due to enhanced gizzard development and increased digesta retention time.

Experiment 6 was conducted as a conclusive study that investigated the effects of two dietary inclusion levels of CC and three different floor types on broiler live performance, litter characteristics, GIT development, apparent ileal digestibility of energy and nitrogen, intestinal morphology, and ammonia emission. Corn grinding cost by hammermill and roller mill was also compared. Feed manufacturing electrical costs of the diet containing 50% CC was 9.47 cents per ton less than 100% fine corn diet. Broilers fed diets containing 50% CC exhibited improved AdjFCR, increased BW, and reduced litter moisture and nitrogen. Raising broilers on NL resulted in a similar effect as dietary CC, indicating broilers may need a coarse textural component in their diet to facilitate gastric development and function.

In conclusion, this dissertation presents evidence that dietary CC inclusion improved broiler live performance and apparent ileal digestibility of energy and nitrogen, but this response is confounded by a decrease in pellet quality. Dietary CC inclusion decreased pellet quality by increasing the percentage of fines, which decreased the feed intake and consequently reduced growth performance. By feeding broilers screened whole pellets during the grower and finisher phase, the confounding effect of pellet quality was removed, and birds exhibited a clearly positive effect of CC on growth performance and nutrient digestibility.

Secondly, the improvements in growth performance and nutrient digestibility by dietary CC inclusion were attributed to modulated GIT motility, development, and function. Dietary inclusion of CC stimulated gizzard activity and enhanced its function, and thereby altered GIT function. Gizzard weight increased linearly as the dietary inclusion level of CC increased, which concluded as a logical consequence of enhanced mechanical grinding activity. Enhanced gizzard function by dietary CC inclusion influenced the GIT motility, development, and function through better gizzard-proventriculus synchrony and gastric digestion, extended digesta retention time, and increased intestinal villi length and total surface area. Consequently, water absorption increased, apparent nutrient digestion and absorption improved, which resulted in reduced N and moisture excretion into the litter. The greater retention time of intestinal digesta may be contributed by enhanced reverse peristalsis and the screen effect of the gizzard. Dietary inclusion of CC altered colon (hindgut) bacterial population profile towards a more symbiotic microflora, which may be due to the improved digestion and absorption of starch, protein, and fat in the foregut that would otherwise serve as residual substrate for hindgut pathogens. Thus, birds may adjust their mechanical, enzymatic, and bacterial digestion according the nutritional and structural composition of their diet.

Thirdly, we should give more credit to the effect of particle size distribution within the diet of commercial poultry than average particle size as typically considered. Particle size of feed ingredients plays a paradoxical role in digestion for poultry, as the larger particles "normalizes" gizzard activity and GIT function, while the smaller particles are more easily agglomerated in a pellet and subsequently digested in the small intestine. We used a blend of corn ground by hammermill and roller mill to create a biphasic distribution of particle sizes, but a similar particle size distribution profile may be achieved by hammermill alone by altering hammer tip speed and screen hole size. The few larger corn particles in the diet are intended to stimulate gizzard function and while the remaining smaller corn particles serve to improve pellet quality, digestion and nutrient absorption. Therefore, the reason for the inconsistent results on optimal grain particle size reported in the literature is because particle size distribution was not properly assessed. Based on our research, we conclude that about 10% of the corn particles in grower and finisher diet should be over 1500 microns in diameter with a dgw of 500 to 600 micron.

Finally, the dietary inclusion of CC was observed to decrease litter moisture and nitrogen content, which is associated with decreased ammonia emission. According another unpublished chamber study, CC treatment significantly decreased the litter ammonia concentration of broilers at 35 d of age. This research demonstrated that dietary CC inclusion could be a very practical and economically feasible method to decrease the occurrence of wet litter and reduce ammonia emission, which may not only improve broiler welfare, but also enhance environmental sustainability.