ABSTRACT

AUTTAWONG, SATID. Impact of Ground Corn Particle Size and Distribution on Pellet Quality, Live Performance of Broilers, and Proventriculus and Gizzard Weights. (Under the direction of Dr. John T. Brake).

Three experiments were conducted to evaluate the effects of partial replacement of various coarsely ground corn (CC) particle size and distribution on pellet quality, broiler live performance, carcass composition, and intestinal organ weights. Chapter II evaluated the effect of CC and post-pellet liquid fat application. Standard and modified pellet durability index (PDI) decreased ($P \leq 0.01$) as inclusion of CC and mixer fat increased. The CC improved feed conversion ratio (FCR) ($P \leq 0.05$) while 3.00% mixer fat addition produced poorer FCR ($P \leq 0.05$) at 28 d only.

Chapter III evaluated the effect of various CC particle sizes (522, 848, 1,223, 1,721, and 2,378 µm). Improved modified PDI was observed ($P \leq 0.05$) in the presence of the largest CC. The FCR was poorest ($P \leq 0.05$) in the CC1600 treatment at 21 d only.

Chapter IV evaluated the effect of various CC particle sizes (349, 798, 1,276, and 1,602 µm) and distributions in the presence of fine and coarse expeller soybean meal (ESBM; 314 versus 1,413 µm). Standard PDI but not modified PDI was best in the CC400 treatment ($P \leq 0.05$). Standard and modified PDI were decreased ($P \leq 0.01$) by diets with coarse ESBM (CESBM). Improved BW at 43 d of age was observed with CC800 treatment as compared to CC1200 with CC400 and CC1600 treatments intermediate ($P \leq 0.05$). Further, FCR was improved at 43 d with CC800 and CC1200 treatments being better than the CC400 diet with CC1600 treatment intermediate ($P \leq 0.05$). Improved BW was evident at 43 d of age ($P \leq 0.05$) and improved FCR at 22 d was observed in broilers fed CESBM ($P \leq 0.05$). Relative gizzard weight was smallest in broilers fed the CC400 treatment diet ($P \leq 0.01$).

The data from Chapter II suggested that partial replacement of fine corn with approximately 800 µm CC was probably appropriate for broilers under 28 d of age but larger CC particle size was required at older ages. Further, data from Chapter III implied that corn particle size may not be the only factor that influenced GIT development and subsequent live performance. Particle size of solvent extracted SBM observed in Chapters II (1,079 µm) and III (1,164 µm) was larger than expected (expected approximately 600-800 µm) and masked the effect of 20% CC. Chapter IV demonstrated that inclusion of CC particles over 1,190 µm at approximately 20% of the diet exhibited an important role in gizzard development and benefited feed efficiency. Coarse ESBM particles had no effect on relative gizzard weight and overall feed efficiency in this study, probably because it was too soft.

Standard PDI data demonstrated and confirmed that greater surface area was associated with improved pellet quality. However, data implied that pellet quality was not necessarily negatively influenced by larger corn particles if feed was appropriately formulated by including a pellet binder and an ingredient such as wheat that has pellet binding characteristics. Nevertheless, decreased pellet quality of less than 5% had no effect on broiler live performance.

Collectively, these studies confirmed that diets containing large feed ingredients decreased PDI. However, this was not meaningful due to the improved feed efficiency, which would be critical for a cost competitive operation. Therefore, both corn particle size and SBM particle size that varied due to processing type, tempering method, and grinder screen size used should be considered in an overall feed particle size strategy.

Impact of Ground Corn Particle Size and Distribution on Pellet Quality, Live Performance of Broilers, and Proventriculus and Gizzard Weights

by
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DEDICATION

This dissertation is dedicated to my family, who supports with an abundance of love that enables me to walk through the path of my life.

BIOGRAPHY

Satid Auttawong, son of Duangjan Auttawong and Fongnual Khuankaew, was born August 11, 1974 and grew up in Chiang Rai, Thailand. He completed his elementary education at Phanpasoksawad School, Chiang Rai, Thailand in 1986 and completed his high school education at Phanphisetphitthaya School, Chiang Rai, Thailand in 1992. In June 1992, he entered Khon Kaen University and received his Doctor of Veterinary Medicine degree in March 1998. He began his career with Laemthong Group as a poultry veterinarian from 1998 to 2000. He then joined Charoen Pokphand Group in 2000 in their Animal Health and Technical Service Office. In 2007, he joined the Feed Technology Office of Charoen Pokphand Group. In 2010, he received a scholarship from the company to pursue his graduate studies. After completing his master's degree in 2012, he then continued his doctoral research under the guidance of Dr. John T. Brake in the Prestage Department of Poultry Science at North Carolina State University.

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I would like to take this opportunity to extend my appreciation to my advisor, Dr. John T. Brake, who always provides me with a chance to prove myself, and for his mentorship, understanding, patience, guidance, and friendship throughout my academic career. We have learned together with expected and unexpected results, which will always be in my memory. Appreciation is also expressed to Dr. Charles R. Stark, Dr. William L. Flowers, Dr. Adam C. Fahrenholz, and Dr. C. Michael Williams for serving as my graduate committee members, and Dr. Van Den Truong for his support as my graduate school representative.

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LIST OF ABBREVIATIONS

AdjFCR	Adjusted feed conversion ratio, corrected for weight of mortality
BW	Body weight
C	Celsius
cm	Centimeter
d	Day
E	Embryonation day
FCR	Feed conversion ratio
g	Gram
h	hour
kg	Kilogram
m	Meter
RH	Relative humidity
wk	Week

CHAPTER I

LITERATURE REVIEW

1.1. INTRODUCTION

Recently, increased feed costs have been associated with an increased demand for corn and soybeans for production of biofuels as commercial poultry feed has been largely composed of corn and soybean meal and feed has been the greatest portion of the total cost of production of meat and egg production. This has dramatically increased interest in improving feed efficiency in the commercial poultry industry. Donohue and Cunningham (2009) estimated that increased feed ingredient costs for broiler production on a percentage of live production cost increased from 51.8% in 2001 to 68.7% in 2008. Further, live production costs for broilers increased by 180% from 2006 to 2008. They also reported that for approximately 98% of the US poultry industry an improvement of 1% in feed efficiency approximately reduced the use of corn by 132.5 million kilograms and use of soybean meal by 61.3 million kilograms annually. Therefore, feed efficiency has become even more critically important for the poultry industry as a means to remain cost competitive.

Feed has been the substance that has maintained constant contact with the gastrointestinal tract (GIT) throughout the life of the chicken. In addition, the GIT has been exposed to a variety of substances due to it being the most extensive exposed surface of the body. Therefore, a wide range of factors associated with feed components and feed characteristics have been found to either negatively or positively affect health status and live performance in commercial poultry production (Yegani and Korver, 2008). For instance, several feed ingredients have been reported to have high levels of anti-nutritional factors, which have led to increased viscosity of GIT contents, decreased intestinal passage rate, decreased enzymatic activities, and decreased availability of nutrients. Those effects have resulted in poorer feed efficiency and decreased growth performance of chickens (Bedford and Schulze, 1998).

Achieving optimal poultry feed efficiency has been generally approached through nutritional specifications. However, nutritional factors may not be the only strategy required to achieve feed efficiency. Many alternative programs had become available for enhancing the performance of poultry and some of these were discussed below. Numerous non-nutritional factors, such as feed processing (Jia and Slominski, 2010), and excellent animal husbandry practices have positively impacted bird live performance (Zhao et al., 2012). There has been an increased interest in improved digestive efficiency through new technology such as feed enzymes (Jia and Slominski, 2010; Kaczmarek et al., 2014), feed additives (Amad et al., 2011), genetically modified grains, and new processing techniques in feed manufacturing (Hott et al., 2008; Loar II et al., 2014; Hafeez et al., 2015).

Nutritional specifications have been developed that meet minimum animal requirements for maintenance, growth, and production but feed characteristics may have the ability to alter GIT organ development and motility, and finally improve the efficiency of digestion and absorption that could modify nutritional strategies. The GIT motility and peristalsis have been recognized for their ability to extend digesta retention time caused by the presence of a relatively short GIT in birds (Moran, 1982).

One prominent approach has involved the manipulation of feed form and feed ingredient particle size in order to promote live performance (Chewning et al., 2012).

Therefore, in the modern feed industry, feed form, pellet quality, and feed ingredient particle size have become major concerns likely to improve feed characteristics and animal live performance. In addition, the interaction between feed characteristics and GIT functions has been recently considered with respect to animal live performance (Favero et al., 2009; Rohe et al., 2014). In general, fine ingredient particles have a benefit in terms of absorption through increased surface area and pellet quality but coarse particles affect GIT morphology and function.

It was therefore necessary to assume that an appropriate increased particle size of feed ingredients would be advantageous in terms of broiler live performance. Thus, more attention was needed to find a balance between particle size, pellet quality, and GIT function. This was why it was so important to consider how feed was prepared, mixed, and manufactured as these factors impacted ultimate nutritional quality and cost of production. The objective was to develop an economical feed manufacturing strategy that enhanced GIT function and reduced cost of production. It was clear that the feed mill will need to become more integral to the feed formulation and GIT function processes.

The following review focused primarily on the poultry GIT and improving broiler live performance through non-nutritional factors such as pelleting and ingredient particle size. This general review was also necessary to further the understanding of how those non-nutritional feed manufacturing factors affected each other, poultry live performance, and GIT development and efficiency.

1.2. AVIAN DIGESTIVE SYSTEM STRUCTURES AND FUNCTIONS

Understanding the unique anatomical and physiological features of the chicken GIT (Figure 1) has become necessary in order to develop a more effective strategy to insure greater efficiency and sustainability of poultry production systems. The avian digestive system acts as a selective barrier between the tissues of the bird and its luminal environment. This barrier has been shown to comprise physical, chemical, immunological, and microbiological components. Duke (1986) suggested that the avian digestive system had been adapted for flight and was relatively light in weight and quite short. The chicken digestive tract begins at the mouth and ends at the cloaca. The GIT has been defined as a continuous tube that consisted of beak, esophagus, crop, proventriculus, gizzard, duodenum, jejunum, ileum, ceca, rectum, and cloaca (Sturkie, 1986). The GIT of avian species was notably different from other animal species due to a distinctive mouth area, the presence of a storage crop in the esophagus, the presence of a two-compartment stomach that included a glandular proventriculus and a muscular ventriculus or gizzard, and ceca.

The primary purpose of the GIT was to break down and digest food into nutrient components, and absorb those nutrients required for growth, maintenance, and production. Digestion consisted of physical and chemical processes. Food was consumed, broken down, mixed with digestive enzymes, and moved along through the GIT by the muscular peristaltic activities of the GIT. Salivary and intestinal secretions provided protection and lubrication. Digestive enzymes catalyzed hydrolysis of numerous compounds into a smaller compounds that were then ready for absorption.

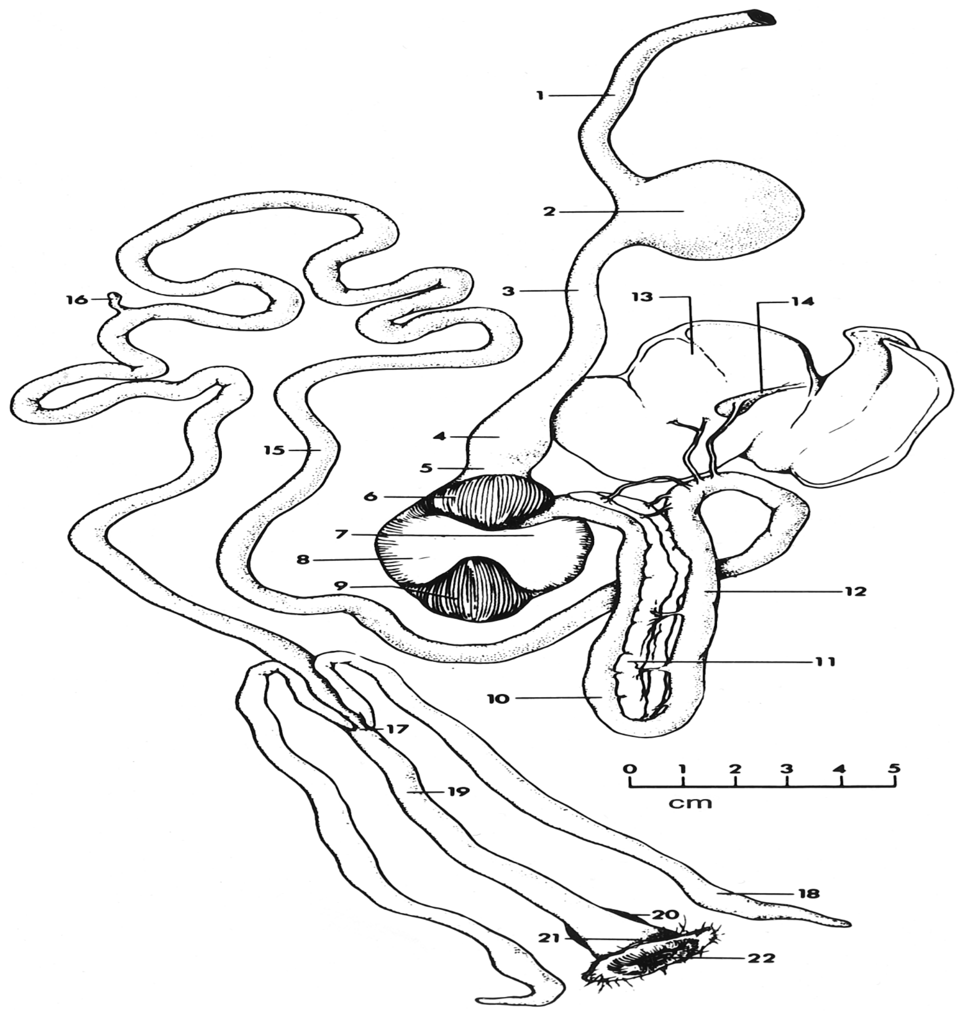

Figure 1. Digestive tract of a 12-wk-old turkey.

1, precrop esophagus; 2, crop; 3, postcrop esophagus; 4, proventriculus; 5, isthmus; 6, thin craniodorsal muscle; 7, thick cranioventral muscle; 8, thick caudodorsal muscle; 9, thin caudoventral muscle; 10, proximal duodenum; 11, pancreas; 12, distal duodenum; 13, liver; 14, gall bladder; 15, ileum; 16, Meckel's diverticulum; 17, ileocecocolic junction; 18, ceca; 19, rectum; 20, bursa of Fabricius; 21, cloaca; 22, vent. (Adapted from Denbow, D. M. 2000.

Gastrointestinal Anatomy and Physiology. Pages 299-325 in Sturkie's Avian Physiology. Whittow, G. C., ed. Academic Press, San Diego).

The oral cavity contained salivary glands that secreted saliva to lubricate the food and ease swallowing. The soft palate and teeth were absent in the avian oral cavity. Therefore, the function of the teeth was achieved primarily by the beak. Birds have been reported to select feed particles according to the size of their oral cavity (Moran, 1982). Pecking was mainly controlled according to the physical characteristics of feed form and feed particle size as perceived by the sensory organs. Pecking behavior has involved an observation period of the feed between exploratory and effective pecks. Visual and tactile cues based on the physical characteristics of feed particles relevant to feed manufacturing has influenced feed identification and prehension (Picard et al., 1999). Sensory organs function through anatomic adaptations for selecting coarse particles for grasping by the beak and propelling the food into the esophagus.

The esophagus was a flexible tube that passed food from the mouth to the crop. The crop has evidently evolved for consuming relatively large amounts of food. The crop has evolved to be a unique feature of avian species located outside the body cavity but as an extended part of the esophagus that functioned as a food storage organ regulating and softening the supply of food to the lower digestive tract. This physiological adaptation of this unique anatomical feature was important in regulating the transit time of digesta during periods without food (Buyse et al., 1993).

The poultry stomach consisted of two main parts that were termed the proventriculus or glandular stomach and the ventriculus (gizzard) or muscular stomach (Moran, 1982). The proventriculus has functioned primarily in production and release of gastric secretions (pepsin, hydrochloric acid, and mucus) while the gizzard has served as the site for mechanical grinding. Secreting cells and alveoli of the proventricular glands were reported to secrete both hydrochloric acid and pepsinogen (McLelland, 1990). Hydrochloric acid and digestive enzymes such as pepsin were mixed with feed to begin digestion in the proventriculus. The proventriculus has been recognized for its importance in protein digestion due to it being relatively small in granivorous and relatively larger in carnivorous and piscivorous species (King, 1984). However, the food had not been ground as it entered the crop so further processing was necessary. The gizzard has become highly specialized to mechanically grind and achieve particle size reduction and surface area increment that provided greater access for enzymes in the small intestine.

The gizzard consisted of two pairs of smooth muscles arranged in distinct perpendicular bands that originated and terminated on a circular tendon (Figure 2). The arrangement of smooth muscles provided mixing and grinding actions during successive contraction. A complex neural network has been found to involve the entire GIT and to facilitate recurring cycles of forward and reverse peristalsis of digesta that provided a longer GIT residence period.

Three distinct phases of reverse peristalsis have been found to be important to optimal digestive function (Duke, 1994). Chickens have utilized reverse peristalsis in combination with forward peristalsis to mix gastric acid, bile, and pancreatic enzymes with feed components.

Peristalsic rushes have been found to be common in chickens. Rushes have been described as a contraction of the intestine occurring as a wave moving throughout the entire length of the intestines in a bi-directional manner, which enhanced optimal absorption of absorbable material from the GIT (Moran, 1982).

The small intestine has been described as having a duodenum, jejunum, and ileum. The duodenum extended from the gizzard to the pancreatic and biliary ducts, and has an attached pancreas within the duodenal loop. The jejunum extended from the pancreatic ducts to Meckel's diverticulum where the ileum continued to the ileo-caecal junction. The intestinal wall was composed of multilayers containing mucosa, submucosa, muscular tunics, and serosa. As incubation progressed, embryonic small intestinal weight has been found to increase at a much greater rate than BW. During the last 3 d of incubation, the small intestinal weight including the external muscular layers and the villi were found to be growing rapidly as their size relative to BW increased from approximately 1% at 17 d of incubation to 3.5% at hatching (Uni et al., 2003).

The small intestine of the newly hatch chicks was reported to be immature and subsequently underwent major morphological and biochemical changes during the first 2 wk post-hatching. At hatching, enterocytes were small, round shaped, and lacked a well-defined brush border. The ontogeny of chick enterocytes has been divided into two periods. In the first 24 h post-hatching, enterocytes acquired polarity and a distinct brush-border membrane, which may not be overcome at later stages in life. The second period involved hypertrophy, which was expressed mainly as increased cell length (Geyra et al., 2001).

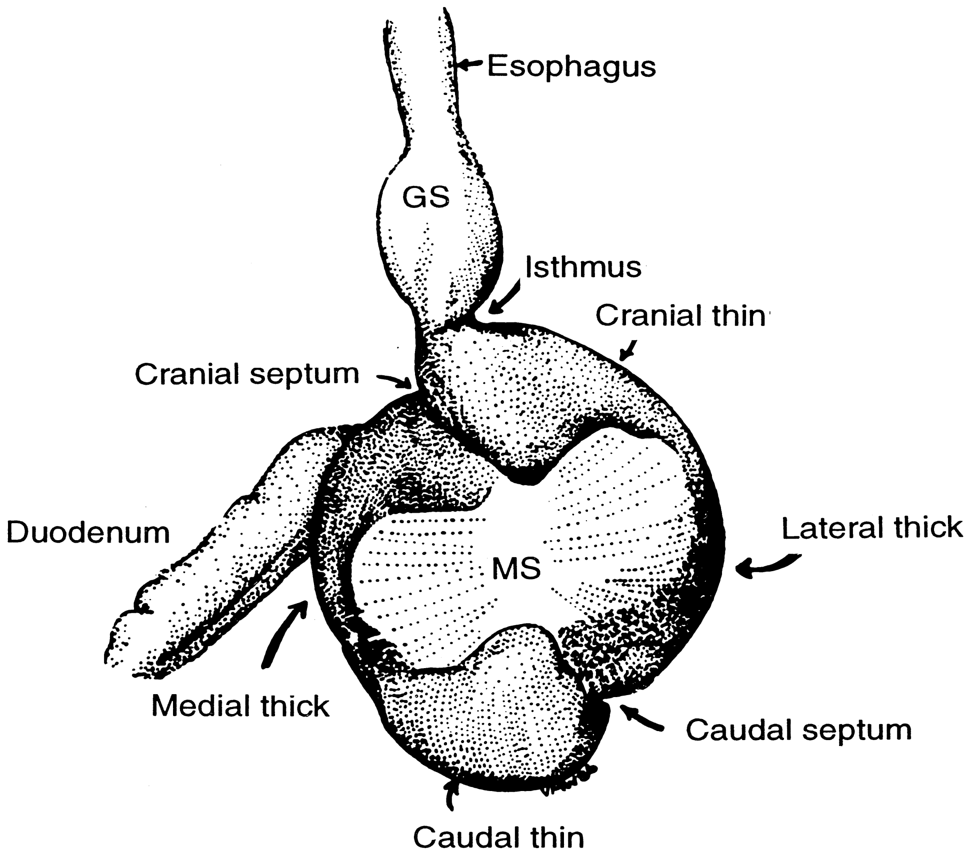

Figure 2. Anatomical features of stomach of domestic turkeys.

The cranial thin muscle of gizzard has been described as continuous with the lateral thick muscle and separated from caudal thin muscle at the caudal septum. Similarly, the caudal thin muscle has been described as continuous with the medial thick muscle and separated from cranial thin muscle by the cranial septum. (Adapted from Denbow, D. M. 2000. Gastrointestinal Anatomy and Physiology. Pages 299-325 in Sturkie's Avian Physiology. Whittow, G. C., ed. Academic Press, San Diego).

In the post-hatching period, the small intestine continued to increase in weight more rapidly than the remainder of the body. However, increased intestinal weight and length were not identical in the duodenum, jejunum, and ileum. The jejunum weight increased more rapidly than duodenum and ileum, whereas length of jejunum and ileum increased twofold over that of the duodenum to 12 d of age. Intestinal development after hatching was also found to achieve its maximal proportion relative to BW between 6-7 d of age and decreased thereafter. The GIT developed rapidly with respect to enzymatic and absorptive activities during this period (Uni et al., 1999).

In addition, it has been shown that during the initial 48 h post-hatching, the yolk sac contributed to small intestinal maintenance and development. During this period, the chick made the transition from utilizing energy in the form of lipids supplied by the yolk sac to utilization of exogenous carbohydrates and protein-rich substrates, which were low in quantity immediately post-hatching and then digestion of nonlipid materials increased rapidly and reached 80% or greater by 4 d of age (Noy and Sklan, 1999). This was confirmed by Sklan (2001) who stated that yolk had been thought to provide nutrients to hatched chicks for the first few days of life but chicks were also found to be ready for exogenous feed that facilitated the transition from the use of lipid-rich yolk to exogenous carbohydrates and proteins. Early access to exogenous feed has been shown to stimulate growth and development of the GIT and also enhance post-hatching utilization of yolk by the small intestine. Birds exhibited rapid intestinal changes in terms of crypt formation, enterocyte morphology, and villus length, width, and surface area increments when access to feed was provided immediately post-hatching.

Most digestion and absorption has been found to occur in the intestines with the aid of digestive enzymes and bile secreted by the pancreas and liver. Absorption primarily has occurred through the mucosa of the small intestine. The interior mucous membrane was comprised of villi with a folded appearance and well-defined network of blood capillaries involved in absorption of nutrients. Between the villi were the crypts of Lieberkuhn where crypt cells proliferated and then migrated to a villi tip. Inner circular and outer longitudinal intestinal muscle layers were responsible for mixing and propelling the digesta through the entire intestine. Nutrients were absorbed and distributed to the body through the portal blood vessels that carried blood from the intestines to the liver.

The liver, gall bladder, and pancreas have been described as the accessory organs of the digestive system. The pancreas was attached within the duodenal loop. The digestive enzymes were produced in the tubular glands of the pancreas and contained enzymes such as amylase, lipases, trypsin, and chymotrypsin. The pancreas also produced insulin that regulated blood glucose and bicarbonate that buffered the GIT. The liver was primarily responsible for the production of bile acids and bile salts, which were secreted into the bile ducts and stored in the gall bladder or secreted directly into the duodenum as the bird has the unique presence of two bile ducts. This has emphasized the point that bile was utilized continually during digestion in a chicken rather than being secreted in response to a specific meal.

1.3. GASTROINTESTINAL MOTILITY AND ITS REGULATION

Physiological appetite has been described as being controlled by hypothalamic centers. There were many factors that have been identified as being involved in regulating this process such as environmental temperature and dietary content. Signals arrived at the cerebral cortex or hypothalamus and stimulated nerves that passed through the hypothalamus. Many of these signals came directly from feed itself; color, shape, and smell. Gleaves et al. (1968) found that dietary energy, protein, weight, and volume directly affected feed consumption. Food was swallowed into the esophagus by peristalsis and subsequently moved into the crop. Extension of the neck and head apparently have played a secondary role in swallowing. The movement of digesta from crop to two-compartment stomach was thereafter controlled by the distention of the stomach and intestines.

As mentioned above, the structure of the gizzard consisted of two pairs of muscles (thin muscles; craniodorsal and caudoventral muscle, and thick muscles; cranioventral and caudodorsal muscle) (Figures 3A and 3B). To compensate for the relatively short digestive tract, avian species have developed a complex neural network that has facilitated recurring cycles of peristalsis of digesta to prolong the period of access by digestive enzymes. The avian GIT has carried out distinct peristaltic movements that have been found to be important to optimal digestive functions. The gizzard, proventriculus, and duodenum were described as coordinated in a gastroduodenal sequence (Duke, 1982) comprising: 1) contraction of the pair of thin muscles, 2) duodenal contraction as one to three peristaltic waves passed through the duodenum, 3) contraction of the pair of thick muscles, and 4) contraction of proventriculus as a peristaltic wave passed through the glandular stomach. During the contraction sequences the pair of thin muscles of the gizzard contracted first. Secondly, two to three peristaltic waves have been found to pass through the duodenum. Next, the pair of thick muscles contracted, and lastly a peristaltic wave passed through the proventriculus. In the contraction of thin and thick muscles, a wave of contraction proceeded in a counterclockwise direction across each muscle. During each gastroduodenal contraction sequence digesta flowed from the gizzard into the duodenum at the end of the contraction of the thin muscles and into the proventriculus during contraction of the thick muscles. During the contraction of the proventriculus, the digesta contents were refluxed to the gizzard (Duke, 1977). The movement of digesta mainly occurred in 4 intestinal regions: 1) proventriculus and gizzard, 2) gizzard and small intestine, 3) small intestine and rectum, and 4) rectum and cloaca (Duke, 1994). The movement of digesta between the proventriculus and gizzard was considered to necessarily optimize the action of enzymatic and mechanical digestion (Duke, 1982). The gastric reflux allowed material in the gizzard to re-enter the proventriculus for additional mixing with acid and pepsin. This was necessary for optimum activity of trypsin and chymotrypsin produced by the pancreas and secreted into the duodenum. The second reflux moved from the duodenum and jejunum back to the gastric area and exposed digesta to a second or third cycle of digestive activity and effectively slowed the rate of digesta passage through the GIT.

Figures 3A and 3B. Gizzard components.

(1) caudodorsal thick muscle (2) cranioventral thick muscle (3) craniodorsal thin muscle (4) caudoventral thin muscle (5) tendinous centre. (Adapted from McLelland, L. J. 1990. Digestive system. Pages 47-65 in A Color Atlas of Avian Anatomy. McLelland, J., ed. Wolfe Publishing, Ltd. Aylesbury, England).

Gastrointestinal contractions have become recognized as a part of an important strategy to compensate for morphological disadvantages due to birds having a significantly shorter and smaller GIT than most animal species. Peristalsis rushes have been described as a contraction of the intestine that occurs as a wave moving throughout the entire intestines bi-directionally. This system promoted optimal absorption in the GIT (Moran, 1982). The rate of passage through the entire GIT was influenced by several factors such as the consistency, hardness, bird age, and water content of the food as well as amount of feed consumed. The passage rate in young chicks was faster than adults (Duke, 1977). Therefore, avian have developed the ability to utilize a combination of intestinal reverse peristalsis and forward peristalsis to mix intestinal secretions and feed components to enhance digestion and also slow the passage rate of the digesta to provide more time for absorption by the intestinal cells.

1.4. EFFECTS OF FEED FORM ON CHICKENS

For commercial poultry production, broilers have been genetically selected to consume feed rapidly so they grow rapidly. Rapid growth has the added benefit of improved feed efficiency due to less body maintenance expenditure over the shorter growing period. Furthermore, Choct (2009) stated that commercial broiler growth rate and feed efficiency have continuously improved due to genetic selection, intensive animal husbandry, and nutritional knowledge so that the growth period has been progressively shortened. Nevertheless, optimum growth rate and live performance will be achieved only if chickens consumed properly formulated feed and efficiently digest that feed. However, maximum feed consumption has depended upon several factors such as feed characteristics, environmental temperature, husbandry, and health status. The physical characteristics of the feed have recently become a subject of increased importance in commercial broiler production. Feed intake can be significantly influenced by feed form. A poor physical feed form has negatively affected feed intake and had a subsequently negative effect on growth rate and performance (Dozier III et al., 2010). Therefore, it was important that feed form was optimal in order to maximize feed intake. Non-nutritive factors, such as pelleting with heat, moisture, and pressure to form finely ground particles into a larger particle has been generally recognized as providing positive benefits. Behnke (1998) outlined the benefits of pelleting as including decreased ingredient segregation, increased digestibility, reduced energy required for prehension, thermal modification of starch and protein, and increased palatability. Pelleting has been considered to have played an important role in feed efficiency and reduced live production costs.

Commercial broilers have been generally provided a diet that has been through the pelleting process. Feeding broiler chickens in crumble or pellet form has been practiced worldwide as this increase the rate of growth due to an increased rate of feed consumption. The effects of feeding crumbles or pellets on growth performance have been studied by several authors. Jensen et al. (1962) found that chicks fed pelleted diets spent four-fold less time eating than chicks fed mash diets and Runnels (1976) reported that pelleting increased BW and improved feed efficiency at 4 wk of age. In general, pelleted feed has improved broiler growth rate due to a greater feed intake (Choi et al., 1986; Amerah et al., 2007; Dozier et al., 2010; Chewning et al., 2012; Serrano et al., 2012; Xu et al., 2015) as well as improved feed efficiency (Amerah et al., 2007; Chewning et al., 2012; Serrano et al., 2012; Xu et al., 2015). These improvements have been attributed to increased nutritional density, improved starch digestibility resulting from chemical changes during pelleting, reduced feed spillage, and decreased energy expenditure for prehension and consumption (Amerah et al., 2007). Therefore, it has become generally known that pelleted diets improved broiler growth rate due to increased feed consumption and that rapid growth rate was probably related to rapid feed consumption. This was also in agreement with Bennett et al. (2002) who reported that feeding mash slowed broiler growth at all ages and clearly demonstrated the widely known principle that growth was proportional to feed consumption. Brickett et al. (2007) reported that growth rate was significantly influenced by feed form as growth rate decreased when diets were fed as mash due to a reduction in feed intake, which was likely a reflection of the reduced ability of birds to consume bulkier and possibly less palatable feed. In addition, broilers fed pelleted diets exhibited greater villus height and crypt depth when compared with broilers fed mash diets, which indicated a general increase in the digestive and absorptive capacity of the small intestine in response to the greater flow of nutrients (Amerah et al., 2007).

1.5. EFFECTS OF PELLETING AND PELLET QUALITY ON CHICKENS

Pelleted feed has been utilized extensively in the commercial broiler industry. The objectives of pelleting have been basically to take various finely ground feed ingredients through moisture, heat, and pressure and form them into larger particles that facilitated rapid feed consumption. Heat was generated in the conditioner where steam was added. It has been understood that mechanical shearing in the pellet die caused additional frictional heating, where gelatinization occurred and allowed the animals to better utilize the nutrients in ingredients. Behnke (1998) demonstrated that the pelleting process has benefits in terms of decreased ingredient segregation, increased digestibility, and increased palatability. In general, studies have supported the principle that pelleted diets positively affected growth performance due to improved feed uniformity and balanced composition of intake. The improvement in live performance of broilers fed pelleted diets was partly due to increased feed intake and partly due to less energy being used for prehension. Therefore, the energy available for growth was increased. However, feeding pelleted diets was not always sufficient to effectively optimize performance of poultry. A frequent problem has been poor pellet quality as a result of production issues, transportation, handling, and mechanical feeding systems.

Although pelleting has been a costly process, the benefits of a good pellet quality have been discussed and recognized. Therefore, alternative ways were needed to reduce pelleted feed manufacturing costs without compromising the live performance of broiler chickens. Optimizing feed efficiency and live production performance at low costs have become increasingly important in the competitive poultry industry. Good pellet quality has always increased feed consumption and therefore poultry growth rate. Thus, the effects of pellet quality on broiler live performance have remained an important subject of scientific investigation and practical management. In general, broiler chickens fed high quality pelleted diets exhibited advantages in feed consumption and growth rate when compared to chickens fed poor quality pelleted diets. Many studies have shown that the non-nutritive factor of excellent pellet quality significantly enhanced BW gain, conversely feed consumption decreased as pellet quality decreased. Greenwood et al. (2004) investigated the effects of percentage fines and found that increased fines was associated with a gradual depression on BW gain and feed consumption. Dozier et al. (2010) also found that broilers fed pelleted diets of high quality with approximately 88-90% PDI grew faster and consumed more feed than broilers fed pellet diets of low quality with approximately 66-68% PDI. This improvement could potentially decrease the number of rearing days to market. McKinney and Teeter (2004) observed the effects of quality of pelleted diets on broiler growth performance. It was clear that feed consumption increased numerically in birds fed pelleted diets when compared with birds fed mash diets but neither pelleting nor pellet quality significantly impacted feed consumption in that study. However, pellet quality has influenced BW gain and feed efficiency when compared with mash diets. It seemed that pellet quality was not always associated with feed consumption. Some improvements were associated with the effective caloric value (ECV) concept, which expressed the energy required by a broiler relative to determined growth and FCR under specific conditions. As pellet quality increased, the effective caloric value (ECV) of diet became greater, which represented decreased energy expenditure for obtaining feed. Therefore, chickens spent less time eating and rested more frequently when pellet quality was improved. Maximum energy savings due to pelleting was 187 kcal ME_n/kg of feed consumed when pellet quality was 100% and minimum energy sparing attributable to pelleting still appeared to be 76 kcal ME_n/kg of feed consumed when pellet quality was 20%. These data also suggested that responses to pellet quality appeared to be biphasic with an intermediate plateau in the 40-60% PDI range. This finding suggested that 40% pellet quality was the minimum pellet quality required to elicit positive effects from the pelleting process. Thus, there was little need to improve pellet quality above 40%, unless pellet quality exceeded 60%.

There were numerous factors that have affected pellet quality that included feed formulation, particle size, conditioning, die specifications, cooling, and drying (Turner, 1995). Feed ingredients have often strongly affected pellet quality with increased protein content (16.3% versus 21.0%) associated with increased PDI and increased oil content associated with decreased PDI when the dietary oil content exceeded 7.5% (Briggs et al., 1999). These data illustrated the negative effect of high dietary fat on pellet quality. Moisture addition prior to the pelleting process improved starch gelatinization, which ultimately increased pellet quality (Moritz et al., 2002). Furthermore, increased residence time inside the steam conditioner allowed the mash to be more adequately conditioned prior to pelleting, which produced better pellet quality (Briggs et al., 1999). Poultry feed has been mainly comprised of corn. It has been generally thought that smaller particle size has contributed to improved pellet quality. Wondra et al. (1995) reported that PDI improved from 78.8 to 86.4 as corn particle size decreased from 1,000 µm to 400 µm. Fine particles were found to accept more moisture during conditioning due to a greater surface area (Turner, 1995). Thus, major feed ingredients in modern broiler feed mills have been generally ground to smaller particle sizes, which have been typically recommended to improve pellet quality.

However, the grinding and pelleting processes have been generally considered to be the most costly parts of feed manufacturing and the benefits of pellet quality have been a subject of debate as discussed above. Therefore, it was desirable for companies to be able to produce optimal pellet quality and minimize feed manufacturing costs while still supporting enhanced growth performance. There was potential for feed manufacturing to be a cost saving unit that reduced overall live production costs from both feed manufacturing and animal production perspectives.

1.6. EFFECTS OF FEED INGREDIENT PARTICLE SIZE ON CHICKENS

Broiler diets in the USA have generally been based primarily on corn and soybean meal so the recently increased price of these ingredients have continued to put pressure on poultry companies as they seek to maintain profitability. The combination of increased feed mill associated costs and expensive feed ingredients have created a demand for new strategies to control live production costs while still optimizing the efficiency of broiler production. Feed ingredients have been traditionally ground in the USA before mixing. The system of grinding after mixing of ingredients has been more popular in other countries such as those in the EU as it was thought that this practice improved pellet quality. Particle size reduction has been a process that involved the disruption of the outer seed coat and the exposure of endosperm resulting in increased surface area, thus allowing for greater interaction with digestive enzymes. Other benefits have included improved ease of handling and mixing characteristics (Goodband et al., 2002). Hammermills and roller mills have been commonly used to reduce the particle size of feed ingredients. Hammermills have accomplished size reduction by impacting a grain with a moving hammer. Particles produced using a hammermill generally have been spherical in shape and the distribution of particle sizes varied around the geometric mean diameter. Roller mills have accomplished size reduction by the combined forces of shearing and compression. The particles produced were somewhat uniform in size but with irregular particles, more cubic or rectangular than spherical (Koch, 1996).

In modern USA feed mill operations most of the major ingredients have to be ground before mixing to particles of various sizes depending on the feed type and feed manufacturing process. The purpose of grinding feed ingredients has been to improve digestibility, improve binding ability between particles during pelleting, improve the mixing efficiency of ingredients, increase particle homogeneity, and prevent ingredient separation. Grinding an ingredient of any size has required significant energy and has added cost to feed production. It has been believed that larger particle size would decrease hammermill energy consumption and production cost. A reduced energy requirement was observed as a result of the increased grinding rate facilitated by increasing the screen size from 4.76 to 6.35 mm that resulted in 114 μm difference in particle size, 910 versus 1024 μm, respectively (Reece et al., 1986). Thus, it was necessary to determine an optimum particle size to ensure adequate utilization at which broiler performance was maximized and production cost was minimized.

Many studies have been conducted regarding the optimum particle size for efficient poultry feed production and feed utilization by the bird. The physical form of feed components may have affected the morphological and physiological aspects of the GIT (Engberg et al., 2004). Apparently, the benefits of feeding larger particle sizes and whole grains to poultry has received considerable attention in recent years. It has been hypothesized that feeding whole grains or larger particle sizes of ingredients improved the health of chickens as well as strongly influenced GIT development, gut motility, and gut functions (Nir et al., 1995; Amerah et al., 2007). Studies that have been conducted on the effects of particle size clearly suggested that grain particle size was quite critical in mash diets. However, there has been controversy concerning the effects that fine particles versus larger particles in pelleted diets have on broiler live performance. Research has linked length of growing period to these effects as older birds that consume more feed appeared to benefit more from larger particles. Further, nutrient utilization was reported to be suboptimal in newly hatched chicks but improved as the broilers aged. Beneficial effects on GIT development has resulted from early feeding (Noy and Sklan, 1999) so it may be beneficial to have exposed chicks to diets containing some large particle size ingredients as early as possible if these birds were to be grown to a larger BW at a later age.

Reece et al. (1985) found that chicks fed mash diets based on corn ground by roller mill (1343 μm) significantly improved BW and feed efficiency, and reduced energy required for grinding corn by 14.5% when compared to chicks fed corn ground by hammermill (814 µm). In addition, improved feed efficiency was observed with 3-6 wk broilers fed a corn particles range of 781-1042 µm, however, feed efficiency was decreased when corn particles exceeded 1,042 µm (Parson et al., 2006). Jacobs et al. (2010) reported that chicks fed a corn particle size range that varied from 557, 858, 1,210, and 1,387 µm resulted in increased relative gizzard weight as particle size increased up to the largest corn particle size of 1,387 micron without compromising growth performance. Furthermore, the effects of particle size of other grain ingredients have been conducted. Nir et al. (1990) conducted the effect of sorghum particles that were ground either by hammermill or roller mill to different particle size; fine (536-574 µm), medium (671-733 µm), and coarse (871-905 µm). Feed consumption, BW gain, and feed efficiency were not affected by the method of grinding but feed consumption and BW gain were increased in the diets containing the coarser particle size. This confirmed the concept that chicks preferred coarse particles, which may be related to beak dimensions. As chicks became older, their preference for larger particles increased. Nir et al. (1995) studied the effect of wheat and sorghum particles that were ground by hammermill (681, 628 µm) and roller mill (1,413, 2,174). Broilers fed coarser particles exhibited an improvement in live performance and relative proventriculus, gizzard, jejunum and ileum, and all GIT component weights. In contrast, Douglas et al. (1990) suggested that the improvement in BW gain and feed efficiency of young broilers fed mash diets with either corn or sorghum containing different finely particles (833-947 µm) compared with chicks fed mash diets with different coarsely particles (1470-1800 µm) might have been due to defeating the normal tendency of birds to selectively eat coarse particles that were largely comprised of the less easily digested seed coat that needed to be properly disrupted to ensure water and substrate access for enzymatic digestion. This concept was in agreement with Nir (1994) who demonstrated that decreased corn particle size from 2010 to 897 μm resulted in improved BW gain and feed efficiency in young chicks that could be influenced by the effects of particle size on the GIT.

Studies examining the effect of grain particles in pelleted diet have been inconsistent. Reece et al. (1986) reported that broiler performance was not affected by finely versus coarsely ground corn (679 and 1289 μm) but BW and feed efficiency were improved compared to chicks fed intermediate ground corn (987 μm). Lott et al. (1992) reported the adverse effect of very coarse corn particles in young birds fed a crumbled diet. Smaller particles (716 μm) improved BW gain and feed efficiency compared to larger particles (1,196 μm), which was apparently too large for young chicks to efficiently utilize to support maximum growth. Amerah et al. (2007) reported that with chicks fed wheat-based diets in mash form that coarse grinding exhibited improved BW, feed intake, and feed efficiency but the effects were not observed in chicks fed in pelleted form. This may be explained because the pelleting process further reduced the size of larger particles and minimized the differences in the initial particle sizes. Amerah et al. (2008) also investigated the interaction between cereal grain type (wheat and corn) and particle size (284-297 and 528-890 μm). Overall, the effects of feed particle size varied depending on grain type. The study found evidence that coarser grinding had beneficial effects on BW gain and produced heavier gizzard weight in chicks fed corn-based diets, whereas these were not observed in chicks fed wheat-based diets. However, coarse particles were advantageous in terms of broiler performance due to decreased feed intake and improved feed efficiency. The improved performance produced by larger feed ingredients may be due to large particles being retained in the GIT for an increased period of digestion and absorption. In addition, coarse feed ingredients may contribute to improved performance in broilers through improved intestinal development, especially that of the gizzard. A poorly developed gizzard has been associated with an increased feed passage rate that led to more nutrients being present in the lower GIT where they promoted microbial proliferation. Branton et al. (1987) found that the 28.9% mortality associated with a combination of necrotic enteritis and coccidiosis when diet contained wheat ground with a hammermill decreased to 18.1% when wheat was ground with a roller mill.

Thus, the hypothesis that feeding whole grains or larger particle sizes of ingredients improved live performance probably varied with several factors that were influenced by age of birds (Lott et al., 1992), feed form (Amerah et al., 2007), grain type (Amerah et al., 2008), and distribution of particle sizes in the diet, in addition to particle size per se (Reece et al., 1986). Based on available data, the optimum particle size for broiler diets based on corn or sorghum should be between 600 and 900 µm and that grain particle size was more critical in mash diets than pelleted or crumbled diets (Amerah et al., 2007).

1.7. RESEARCH JUSTIFICATION AND OBJECTIVES

Commercial broiler diets have historically contained a large portion of corn that must be efficiently digested if wastes were to be minimized and the full benefits of the nutritional value of the feed were to be realized. To efficiently manage the rapidly growing modern broiler, it has become necessary to understand how to better manage the complex physiological processes involved in broiler digestion. Many feeding strategies have been implemented to improve broiler feed intake, BW gain, feed efficiency, and optimize the development and function of the GIT. In most cases, the implementation of these strategies considered the use of feed enzymes (Jia and Slominski, 2010; Kaczmarek et al., 2014), feed additives (Amad et al., 2011), and highly digestible ingredients. Gonza´lez-Alvarado et al. (2007) suggested that rice was a highly digestible alternative ingredient for post-hatching chicks because rice was high in starch content and low in nonstarch polysaccharide content and other anti-nutritional factors. However, young chicks might require a minimal amount of fiber in the diet to maximize performance, gizzard activity, and GIT functions (Jimenez-Morenzo et al., 2009; Jimenez-Morenzo et al., 2010).

The benefits of pelleting in the animal feed industry have been recognized because improved performance in broilers fed pelleted diets was partly due to increased feed intake and partly due to less energy being used for prehension. However, feeding pelleted diets was not always sufficient to effectively optimize performance of broilers. In general, broilers fed high quality pelleted diets exhibited advantages in growth rate and feed consumption compared to those fed poor quality pelleted diets. There were numerous factors that affected pellet quality. A frequent problem has been poor pellet quality as a result of production issues, transportation, handling, and mechanical feeding.

It was quite clear that a beneficial effect of coarse particles has been established in mash feed but the effects were not consistently observed in pelleted diets. Nevertheless, it has been suggested that although pelleted feed dissolved in the crop almost immediately after consumption, the beneficial effects of coarse particles may be maintained through increased retention time as a result of enhanced peristalsis and improved feed utilization (Nir et al., 1995). However, larger grain particle size may have a negative effect on pellet quality and therefore poultry feed consumption and live performance. It was necessary to find a balance between the beneficial effects of coarse feed particles and pellet quality. Further, the two major grinding machines, roller mill and hammermill, were known to produce different particle size distributions so determination of the optimal size was required in order to manage these two methods of particle size reduction.

The objectives of the present experiments were to provide the information and understand the effects of major ingredient particle size produced during feed manufacturing that affected pellet quality, broiler live performance, and GIT development. The effects of these factors were determined in terms of PDI, broiler live performance, and proventriculus and gizzard weights.

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CHAPTER II

EFFECT OF DIETARY COARSE CORN AND LIQUID FAT APPLICATION ON PELLET QUALITY, BROILER LIVE PERFORMANCE, AND CARCASS COMPOSITION

2.1. ABSTRACT

A floor pen experiment with new wood shavings litter was conducted to evaluate the effect of coarse corn (CC) and post-pellet liquid fat application on pellet quality, broiler live performance from 1 to 49 d of age, and carcass composition. The 640 Ross 344 x 708 male chicks were assigned to a factorial arrangement of treatments consisting of 2 series of dietary inclusions of CC (0 vs 10%, or 0 vs 20%, or 0 vs 30% of total dietary corn in starter, grower, and finisher diets, respectively) and 4 liquid fat applications (0.75%, 1.50%, 2.25%, and 3.00% in the mixer plus 2.50%, 1.75%, 1.00% and 0.25%, respectively, added post-pellet to give a total added fat content of 3.25% in grower and finisher diets). Each of the 8 treatment combinations was replicated with 5 pens of 16 birds each. Fine corn (FC) was ground with a hammermill to 287 µm (2.4 mm screen) while CC was ground with a roller mill to 806 µm. The FC and CC were blended to create the CC inclusion levels. Pellet durability index (PDI) was determined on samples collected at the pellet mill die as standard and modified PDI with 3 nuts (diameter = 19 mm). Feed intake and BW were determined at 14, 28, 35, 42, and 49 d of age and adjusted feed conversion ratio (AdjFCR) was calculated by including BW of mortality. Carcass yield was evaluated at 50 d of age based upon on the carcass weight without giblets (WOG weight). Standard and modified PDI were decreased ($P \leq 0.01$) as CC increased in grower and finisher diets. Decreased standard and modified PDI were also observed ($P \leq 0.01$) in high mixer fat applications. The poorest standard and modified PDI were observed ($P \leq 0.01$) in the grower and finisher diets in the presence of CC and a mixer fat application greater than 2.25%. Feed intake, BW, and carcass composition were not affected by CC. The AdjFCR was improved ($P \leq 0.05$) by CC at 28 d but the effect was not observed thereafter. The quantity

of mixer fat applied had no effect on feed intake, BW, or carcass composition. However, 3.00% mixer fat addition produced poorer AdjFCR ($P \leq 0.05$) at 28 d but the effect diminished thereafter. Based upon these data, partial replacement of FC with approximately 800 µm CC was appropriate for broilers under 28 d of age. Moreover, the results of the current study suggested that the optimum mixer fat addition to be approximately 1.50% or less in order to maintain pellet quality, especially in the presence of CC in diets.

Keywords: broiler live performance, post-pellet liquid fat application, pellet durability index

2.2. INTRODUCTION

The beneficial effects of large particle size on broiler performance have been clearly demonstrated in mash diets. In pelleted diets, the beneficial results have not been observed as consistently. In addition, pellet quality has been shown to be important to animal live performance and feed material handling. In general, broiler chickens fed high quality pelleted diets have exhibited advantages in growth rate and feed consumption compared to chickens fed poor quality pelleted diets (Greenwood et al., 2004). Pellet quality has been reported to be proportionally dependent on the following factors: 40% formulation, 20% grinding, 20% conditioning, 15% die specifications, and 5% drying and cooling (Fahrenholz, 2012). Poultry feed has historically been primarily composed of corn and soybean meal. Corn has often been finely ground by a hammermill, and particle size was known to be one of the factors that affected pellet quality. Pellet quality and particle size have been inversely related in that smaller particle size has contributed to improved pellet quality (Wondra et al., 1995) due to a greater surface area required to accept more moisture during conditioning (Turner, 1995).

However, it has been debated to what degree greater particle size has negatively affected pellet quality. Actually, there have been limited scientific reports concerning the correlation between corn particle size, pellet quality, and broiler performance. There has been evidence that pellet quality was not affected by corn particle size. Reece et al. (1986) stated that an increased corn particle size from 910 to 1024 µm had no effect on pellet quality. Further, Reece et al. (1986) reported that pellet quality measured as PDI was significantly improved from 91 to 92.5 as geometric mean diameter increased from 679 to 1289 µm, respectively. These data suggested that greater corn particle size influenced pellet quality less than 2%, which may not be meaningful to a commercial integrator.

Fat has been a common energy source in broiler feed, so that addition of fat has become a common practice to increase the energy content of broiler diets. The inhibitory effect of lipids on gut passage rate has increased the digestibility of other nutrients by extending the time of exposure to enzymes and absorptive sites. However, it has been shown that increased oil content decreased pellet quality. Briggs et al. (1999) reported detrimental effects of fat on pellet quality as the oil content exceeded 7.5% when the protein content ranged from 20.3 to 21%. This was similar to Plavnik et al. (1997) who explained that energy supplied by fat could decrease growth rate if there was a reduction in pellet quality, which would negatively affect feed consumption. Hence, high levels of fat required for high energy diets have often been applied post-pellet in order to avoid reduction in pellet quality associated with excessive fat added in the mixer. However, limited data were available concerning the quantity of post-pellet added fat that would not create pellet quality problems.

This study was designed to determine the effects of partial replacement of finely ground corn (FC) with coarsely ground corn (CC) and the quantity of added fat in the mixer on pellet quality, subsequent broiler live performance, and carcass composition. The hypothesis of this study was that increasing CC and increasing mixer added fat would negatively affect pellet quality. Attention was not only given to potential negative effects of the CC and high levels of mixer added fat on pellet quality, but also to any negative impacts on live performance and carcass characteristics.

2.3. MATERIALS AND METHODS

Hatching Eggs and Incubation. A total of 2,880 broiler hatching eggs were collected from 52-wk-old Ross 344 x 708 (Aviagen, Huntsville, AL) broiler breeders maintained at the research site. Preheating was done by moving the eggs into a room maintained at 26 to 28°C for 12 h and then bringing the Jamesway setters to a set point of 38.0°C through E3 of incubation. The dry bulb temperature was then changed to 37.5°C and gradually decreased to 37.5°C from E3 to E12, 37.4°C from E13 to E15, and 37.2°C from E16 to E18 to maintain an internal egg temperature of 37.8°C or slightly below. The dry bulb temperature was independently confirmed daily with a mercury thermometer. Relative humidity was maintained at 53% throughout incubation. Ventilation of the machine with fresh air was at a minimum initially, but was gradually increased after 12 d of incubation.

Broiler Management. The experiment was conducted from August to October, 2013, at the North Carolina State University Chicken Educational Unit, Raleigh, NC. Animal handling conformed to the Guide for Care and Use of Agricultural Animals in Research and

Teaching (FASS, 2010). Broiler chicks were hatched, feather sexed, and maintained separately by breeder pen source before and after sexing. Sixteen male chicks were randomly selected with one chick coming from each breeder pen such that breeder source effects were equalized. Chicks were then permanently identified with neck tags, pen group weighed, and distributed onto new wood shaving litter after manual introduction to water and feed. Each pen had a dimension of 1.2 m width by 1.8 m length and the stocking density was 7.4 birds per m^2. Each pen was equipped with one bell-type drinker and one manual tube feeder. The brooding temperature at reception of 35.0-36.1°C on the litter, which was determined by an infrared thermoscan gun, was maintained through the first night before being decreased to 31.1-32.2°C the following morning. The litter temperature was maintained from 2 to 7 d at 31.1 to 32.2°C, 8 to 14 d at 29 to 30°C, 15 to 21 d at 26 to 27°C, and at ambient temperature thereafter. Water and broiler diets were provided for *ad libitum* consumption. Three supplemental feeder flats were used until 7 d of age, two flats to 10 d, and one flat to 13 d of age. There was 0.45 kg of broiler starter crumbles added per bird at 1 d of age. Small amounts of feed were moved out of the tube feeders onto the feeder flats once daily to 7 d of age. At 13 d of age, about 0.45 kg of broiler starter diet was added to bring the total to 0.9 kg per bird alive. The broiler feeding program was 0.9 kg/bird of starter, 2.7 kg/bird of grower, and 3.6 kg/bird of finisher diets. Feeders were shaken once per day to 14 d, and twice daily thereafter to maintain the flow of feed from tubes into pans. The lighting program schedule was 23 h of light from 1 to 7 d, 21 h of light from 8 to 21 d, and 16 h of light thereafter. House environment and birds were closely monitored and mortalities were weighed and recorded twice daily throughout the experiment.

Feed Formulation and Manufacturing. The experimental diets (Tables II-1, II-2, II-3) were formulated mainly of corn, soybean meal (SBM), and distiller's dried grains with solubles (DDGS). Diets were manufactured at the North Carolina State University Feed Mill Educational Unit. Corn was ground using a hammermill (Model 1522, Roskamp Champion, Waterloo, IA) equipped with two 2.4 mm (6/64 inch) screens to produce fine ground corn (FC). A two-pair roller mill (Model C128829, RMS, Harrisburg, SD) was used to produce the coarse ground corn (CC). A basal mash diet was used to reduce ingredient variation. Dry ingredients were blended in a counterpoise mixer (Model TRDB126-0604, Hayes & Stolz, Fort Worth, TX) to create the basal diet. Each experimental diet was produced from the basal diet with appropriate amounts of either FC or CC and poultry fat added before final mixing in the counterpoise mixer. The mash diet was then conditioned (Model C18LL47F6, California Pellet Mill Co., Crawfordsville, IN) at 82 to 85°C and pelleted with a pellet mill (Model PM1112-2, California Pellet Mill Co., Crawfordsville, IN) equipped with a 4.4 mm X 45 mm die (11/64 inch x 1 ¾ inch). Pelleted diets were cooled with ambient air in a counter-flow cooler (Model VK09X09KL, Geelen Counterflow USA Inc., Orlando, Florida). The remaining fat was added post-pelleting in the counterpoise mixer. The starter diets were produced as crumbles and grower and finisher diets were produced as pellets.

Data Collection. The particle size of ground ingredients were determined by dry sieving according to ASAE method S319.4 (ASABE, 2012; Stark and Chewning, 2012) with the addition of sieve agitators and 0.5 g of a dispersing agent per 100 g of sample (Silicon Dioxide, SSA-58, Gilson, Lewis Center, OH). Pelleted diets were collected at the pellet die before post-pellet fat application. Each treatment diet was collected 4 times at evenly spaced intervals upon discharge from the pellet mill. The pellet durability index (PDI) was determined according to ASAE standard method S269.4 (ASABE, 2007). Initial BW of chicks was determined on a pen group basis and recorded on the day of placement. Thereafter, BW and feed intake were determined on a pen basis at 14, 28, 35, 42, and 49 d of age. All dead birds were removed, weighed, and recorded twice daily. Adjusted feed conversion ratio (AdjFCR) was calculated at 14, 28, 35, 42, and 49 d of age by including BW of all dead birds. At 50 d of age, 120 birds (3 birds per pen) were killed for carcass evaluation. Birds were fasted for 12 h, individually weighed, stunned, killed by exsanguination, and allowed to bleed for 90 seconds. Birds were then scalded at 55°C for 90 seconds in a rotary scalder, picked for 40 seconds in a drum picker, and manually eviscerated. Carcasses were dressed by removing crop, proventriculus, neck, head, feet, lungs, viscera, and giblets (liver, gizzard, and heart) to determine the carcass weight (WOG weight: carcass weight without giblets). Carcasses were then manually deboned on stationary cones. The abdominal fat, legs plus thighs, wings, skin, breast fillets (*Pectoralis major*), breast tenders (*Pectoralis minor*), and rack were dissected and weighed. The carcass yield was calculated as a percentage of the WOG weight.

Data Analysis. Pelleted samples that were collected at the pellet die served as the experimental unit for PDI data. Pen served as the experimental unit for live performance data. The experimental design was a 2 x 4 factorial randomized complete block design with 5 blocks so that each combination was replicated with 5 pens of 16 birds each. Each bird served as an experimental unit for the carcass yield data. The data were analyzed by using the GLM procedure of SAS (SAS 9.4, SAS Institute, Cary, NC, USA, 2014). Two-way ANOVA was used to determine the main effects and their interaction. Differences between means were partitioned by the LS means method and statistical significance was reported at a probability level of $P \leq 0.05$ unless otherwise stated.

2.4. RESULTS AND DISCUSSION

The geometric mean diameter (GMD) and geometric standard deviation (GSD) of ingredients are shown in Table II-4. The result of the dry sieving according to ASAE method S319.4 with the addition of sieve agitators and 0.5 g of a dispersing agent per 100 g of sample (ASABE, 2012) described the difference in particle size between FC and CC. FC ground by the hammermill exhibited smaller particle size and standard deviation than CC ground by roller mill. The particle size distribution of these feed ingredients is graphically shown in Figure II-1.

The main and interaction effects of percentage CC of total dietary corn and percentage mixer liquid fat application in grower diets on pellet durability index (PDI) are shown in Table II-5. An improved standard PDI of 4.2% was evident in grower diets containing FC as compared to diets containing CC ($P \leq 0.01$). Considering the modified PDI, pellet quality was improved by 2.3% in diets containing FC as compared to diets containing CC in grower diets ($P \leq 0.01$). With respect to percentage mixer liquid fat application, adding greater mixer fat to grower diets decreased standard and modified PDI ($P \leq 0.01$), when mixer liquid fat addition was 2.25 or 3.00%. There was an interaction effect of percentage CC of total dietary corn and percentage mixer liquid fat application in grower diets on PDI where the poorest standard and modified PDI were created by mixer fat of 2.25% or greater in the presence of CC ($P \leq 0.01$).

The effects of percentage CC of total dietary corn and percentage mixer liquid fat application on PDI in finisher diets are shown in Table II-6. An improved standard and modified PDI of 6.4% and 5.7% was evident in diets containing FC as compared to diets containing CC, respectively ($P \leq 0.01$). Adding mixer fat to finisher diets decreased standard and modified PDI in a stepwise manner ($P \leq 0.01$). There was an interaction effect of percentage CC of total dietary corn and percentage mixer liquid fat application in finisher diets on PDI where the standard and modified PDI were observed to decrease more rapidly with increasing mixer fat in the presence of CC ($P \leq 0.01$).

These data detailed above confirmed the traditional theory that improved pellet quality was associated with smaller particle size grains (Wondra et al., 1995) due to a greater surface area to accept more moisture during conditioning (Turner, 1995). However, our data were not in agreement with Reece et al. (1986) who reported improved pellet quality as particle size increased. Our data additionally demonstrated that greater corn particle size influenced PDI approximately 5%, which may not have a meaningful effect on live performance as standard PDI exceeded 80% in all cases. Even though fat addition has become a common practice to increase the energy content of broiler diets it has been thought that increased oil content decreased pellet quality (Briggs et al., 1999) as fat has functioned as a lubricant in the pellet die and may have decreased die friction required for pellet binding. However, this study demonstrated that the manner in which fat was applied to a pelleted diet was also important in order to ameliorate the adverse effects on PDI of a high energy diet. The interaction effects were probably due to additional effects of a reduced surface area of CC needed to accept more moisture during conditioning (Turner, 1995) and increased fat content in the pre-pelleting mash diets, which functioned as a lubricant in the pellet die and may have decreased die friction, pellet binding, and resulted in poor pellet quality (Briggs et al., 1999). Based upon the present data, the optimum mixer fat addition was approximately 1.50% or less in order to maintain pellet quality, especially when diets were manufactured with CC.

There were no main or interaction effects of percentage CC of total dietary corn and percentage mixer liquid fat application on FI and period FI as shown in Tables II-7 and II-8, respectively. These data demonstrated the relatively minor effects of pellet quality on feed intake under the conditions of this experiment. The main and interaction effects of percentage CC of total dietary corn and percentage mixer liquid fat application on BW and period BW gain are shown in Table II-9 and II-10, respectively. There were no main and interaction effect on BW and period BW gain.

The main and interaction effects of percentage CC of total dietary corn and percentage mixer liquid fat application on AdjFCR are shown in Tables II-11. Broilers provided with CC exhibited improved AdjFCR at 28 d ($P \leq 0.05$) but this difference was not evident thereafter. There was an improved AdjFCR at 28 d of age ($P \leq 0.05$) with 1.50 and 2.25% mixer fat as compared to 3.00%, with 0.75% mixer fat being intermediate. There was an interaction effect on AdjFCR at 35 d ($P \leq 0.05$). In the presence of FC, AdjFCR was improved with 1.50 and 2.25% compared to 0.75% with 3.00% intermediate. Further, an improved AdjFCR was observed with 0.75 and 2.25% mixer fat compared to 3.00% with 0.75% intermediate in the presence of CC. There was an improved period AdjFCR from 15-28 d ($P \leq 0.05$) with 0.75, 1.50, and 2.25% mixer fat performing better than 3.00% (Table II-12).

An improved AdjFCR at 28 d in broilers fed diets containing CC implied that the positive effect of CC was transient in pelleted diets and broilers required a period of time to fully adapt and utilize larger particle size corn. Nir et al. (1994) reported that birds that consumed diets with different particle sizes of corn (897 versus 1,102 µm) exhibited no significant differences in live performance at 7 d, but live performance improved in birds fed 897 corn particle at 21 d of age. However, the improved AdjFCR diminished thereafter, which suggested that broilers may have required different size corn at different ages in order to maintain gizzard activity and gut motility. Regarding effects of mixer fat addition, improved AdjFCR at 28 d and period AdjFCR were probably associated with pellet quality and hardness. Standard PDI best represented the feed pellet quality in the present study as all experimental diets were bagged and then transported directly to feeders with limited mechanical handling. The explanation for improved AdjFCR and period AdjFCR was therefore pellet quality. Jensen et al. (1962) reported that birds fed pellets spent less time eating when compared with birds fed mash diets. This was expressed by the effective caloric value (ECV) concept described by McKinney and Teeter (2004). As pellet quality increased, effective caloric value (ECV) of diet became greater, which represented a decreased energy expenditure for obtaining feed. The current study showed that pellet quality was decreased approximately 10% with 3.00% mixer fat addition when compared with 2.25% mixer added fat (69% and 82% standard PDI). Therefore, energy saving by the bird due to improved pellet quality from 69% PDI to 82% PDI was calculated to be approximately 23 kcal ME_n/kg of feed consumed. The current study also suggested that pellet quality should be approximately 80% to not compromise AdjFCR. With the unexpected interaction, the only explanation was that it seemed that the hardness of the pellets, which may have been less palatable, was probably affected by the fat applied in the mixer. Therefore, optimizing diet hardness should take into consideration the physical traits of the complete diet as well as pellet quality.

The main and interaction effects of percentage CC of total dietary corn and percentage mixer liquid fat application on depletion are shown in Table II-13. There were no main effects regarding depletion. However, there was an interaction with regards to depletion at 14 d of age. The greatest depletion was observed in the presence of CC with 3.00% mixer added fat ($P \leq 0.05$), which resulted from an accident during routine observation that resulted in dead chicks.

The main and interaction effects of percentage CC of total dietary corn and percentage mixer liquid fat application on carcass parts weight and percentage carcass parts weight are shown in Tables II-14 and II-15, respectively. There were no main and interaction effects on carcass composition.

2.5. REFERENCES

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Table II-1. The composition of broiler starter diets using two percentage coarse corn (CC) of total dietary corn

Ingredients	Percentage coarse corn of total dietary corn 0%	10%
	(%)	
Fine corn	54.98	49.49
Coarse corn	---	5.49
SBM (48% CP)	29.62	29.62
DDGS (26.2% CP)	5.00	5.00
Poultry by-product meal (53% CP)	5.00	5.00
Poultry fat	1.97	1.97
Dicalcium phosphate (18.5% P)	1.18	1.18
Limestone	0.77	0.77
Salt	0.41	0.41
DL-Methionine	0.22	0.22
L-Lysine-HCL (78%)	0.19	0.19
L-Threonine	0.10	0.10
Choline chloride (60%)	0.20	0.20
Mineral premix [1]	0.20	0.20
Vitamin premix [2]	0.05	0.05
Selenium premix [3]	0.05	0.05
Coccidiostat [4]	0.05	0.05
Calculated nutrients		
Protein	23.00	23.00
Calcium	0.90	0.90
Available phosphorus	0.45	0.45
Total lysine	1.31	1.31
Total methionine	0.59	0.59
Total threonine	0.87	0.87
Total methionine + cysteine	0.96	0.96
Sodium	0.19	0.19
ME, kcal/g	2.95	2.95
Analyzed nutrients		
Protein	19.52	19.83
Fat	5.57	4.83
Fiber	2.60	2.50
Ash	5.36	5.58
Moisture	14.05	12.29

[1] Mineral premix supplied the following per kg of feed: Mn 108 mg, Zn 108 mg, Fe 72.6 mg, Cu 9 mg, I 2.2 mg, and Co 2.2 mg.

[2] Vitamin premix supplied the following per kg of feed: vitamin A 6608 IU, vitamin D_3 1982 IU; vitamin E 33 IU, vitamin B_6 3.9 mg, vitamin B_{12} 0.02 mg, biotin 0.13 mg, niacin 55 mg, thiamine 1.9 mg, riboflavin 6.6 mg, menadione (K_3) 1.9 mg, d-pantothenic acid 11 mg, and folic acid 1.1 mg.

[3] Selenium premix supplied Se at 0.3 mg per kg of feed.

[4] Coccidiostat supplied monensin sodium at 99 mg per kg of feed.

Table II-2. The composition of broiler grower diets using two percentage coarse corn (CC) of total dietary corn and four percentage mixer fat addition

	Percentage coarse corn of total dietary corn[1] and percentage added fat as mixer fat[2]							
	0%[1]				20%[1]			
Ingredients	0.75%[2]	1.50%[2]	2.25%[2]	3.00%[2]	0.75%[2]	1.50%[2]	2.25%[2]	3.00%[2]
	(%)							
Fine corn	57.43	57.43	57.43	57.43	45.94	45.94	45.94	45.94
Coarse corn	---	---	---	---	11.49	11.49	11.49	11.49
SBM (48% CP)	23.68	23.68	23.68	23.68	23.68	23.68	23.68	23.68
DDGS (26.2% CP)	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Poultry by-product meal (53% CP)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Mixer poultry fat	0.75	1.50	2.25	3.00	0.75	1.50	2.25	3.00
Post-pellet poultry fat	2.50	1.75	1.00	0.25	2.50	1.75	1.00	0.25
Dicalcium phosphate (18.5% P)	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34
Limestone	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Salt	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
DL-Methionine	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
L-Lysine-HCL (78%)	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
L-Threonine	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Choline chloride (60%)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Mineral premix [1]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin premix [2]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Selenium premix [3]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Coccidiostat [4]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calculated nutrients								
Protein	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Calcium	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Available phosphorus	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Total lysine	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14
Total methionine	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Total threonine	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
Total methionine + cysteine	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
Sodium	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
ME, kcal/g	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05
Analyzed nutrients								
Protein	19.79	20.20	19.90	20.93	21.14	21.23	19.86	20.10
Fat	7.80	7.06	6.11	5.72	6.90	7.01	6.26	6.33
Fiber	2.60	2.70	2.60	2.50	2.60	3.00	2.80	3.20
Ash	5.23	5.21	5.24	4.98	5.49	5.03	5.11	5.24
Moisture	13.57	13.06	13.20	13.25	13.00	13.07	13.09	13.34

[1] Mineral premix supplied the following per kg of feed: Mn 108 mg, Zn 108 mg, Fe 72.6 mg, Cu 9 mg, I 2.2 mg, and Co 2.2 mg.

[2] Vitamin premix supplied the following per kg of feed: vitamin A 6608 IU, vitamin D_3 1982 IU; vitamin E 33 IU, vitamin B_6 3.9 mg, vitamin B_{12} 0.02 mg, biotin 0.13 mg, niacin 55 mg, thiamine 1.9 mg, riboflavin 6.6 mg, menadione (K_3) 1.9 mg, d-pantothenic acid 11 mg, and folic acid 1.1 mg.

[3] Selenium premix supplied Se at 0.3 mg per kg of feed.

[4] Coccidiostat supplied monensin sodium at 99 mg per kg of feed.

Table II-3. The composition of broiler finisher diets using two percentage coarse corn (CC) of total dietary corn and four percentage mixer fat addition

	Percentage coarse corn of total dietary corn[1] and percentage added fat as mixer fat[2]							
	0%[1]				30%[1]			
Ingredients	0.75%[2]	1.50%[2]	2.25%[2]	3.00%[2]	0.75%[2]	1.50%[2]	2.25%[2]	3.00%[2]
	(%)							
Fine corn	61.90	61.90	61.90	61.90	43.33	43.33	43.33	43.33
Coarse corn	---	---	---	---	18.57	18.57	18.57	18.57
SBM (48% CP)	14.16	14.16	14.16	14.16	14.16	14.16	14.16	14.16
DDGS (26.2% CP)	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Poultry by-product meal (53% CP)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Mixer poultry fat	0.75	1.50	2.25	3.00	0.75	1.50	2.25	3.00
Post-pellet poultry fat	2.50	1.75	1.00	0.25	2.50	1.75	1.00	0.25
Dicalcium phosphate (18.5% P)	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34
Limestone	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Salt	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
DL-Methionine	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
L-Lysine-HCL (78%)	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
L-Threonine	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Choline chloride (60%)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Mineral premix [1]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin premix [2]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Selenium premix [3]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Coccidiostat [4]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calculated nutrients								
Protein	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
Calcium	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Available phosphorus	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Total lysine	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Total methionine	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
Total threonine	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Total methionine + cysteine	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Sodium	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
ME, kcal/g	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13
Analyzed nutrients								
Protein	18.64	18.71	17.50	18.43	17.59	17.62	18.81	20.11
Fat	6.92	6.72	6.74	7.54	7.70	7.83	6.70	4.42
Fiber	3.40	3.30	3.40	3.30	3.30	3.20	3.30	2.80
Ash	4.82	4.67	4.82	4.56	4.50	4.94	4.66	4.65
Moisture	13.66	12.90	12.95	12.68	13.00	12.84	12.99	13.69

[1] Mineral premix supplied the following per kg of feed: Mn 108 mg, Zn 108 mg, Fe 72.6 mg, Cu 9 mg, I 2.2 mg, and Co 2.2 mg.

[2] Vitamin premix supplied the following per kg of feed: vitamin A 6608 IU, vitamin D_3 1982 IU; vitamin E 33 IU, vitamin B_6 3.9 mg, vitamin B_{12} 0.02 mg, biotin 0.13 mg, niacin 55 mg, thiamine 1.9 mg, riboflavin 6.6 mg, menadione (K_3) 1.9 mg, d-pantothenic acid 11 mg, and folic acid 1.1 mg.

[3] Selenium premix supplied Se at 0.3 mg per kg of feed.

[4] Coccidiostat supplied monensin sodium at 99 mg per kg of feed.

Table II-4. Mean diameter particle size of ingredients

Ingredients	Dgw[1]	Sgw[2]
	(µm)	
Coarse corn	806	3.22
Fine corn	287	2.64
Soybean meal	1079	2.10
DDGS	553	2.04
Corn gluten meal	301	2.19
Poultry meal	382	2.49

[1] Geometric mean diameter was determined by dry sieving according to ASAE method S319.4 with the addition of sieve agitators and 0.5 g of a dispersing agent per 100 g of sample (ASABE, 2012; Stark and Chewning, 2012).
[2] Geometric standard deviation of mean particle size.

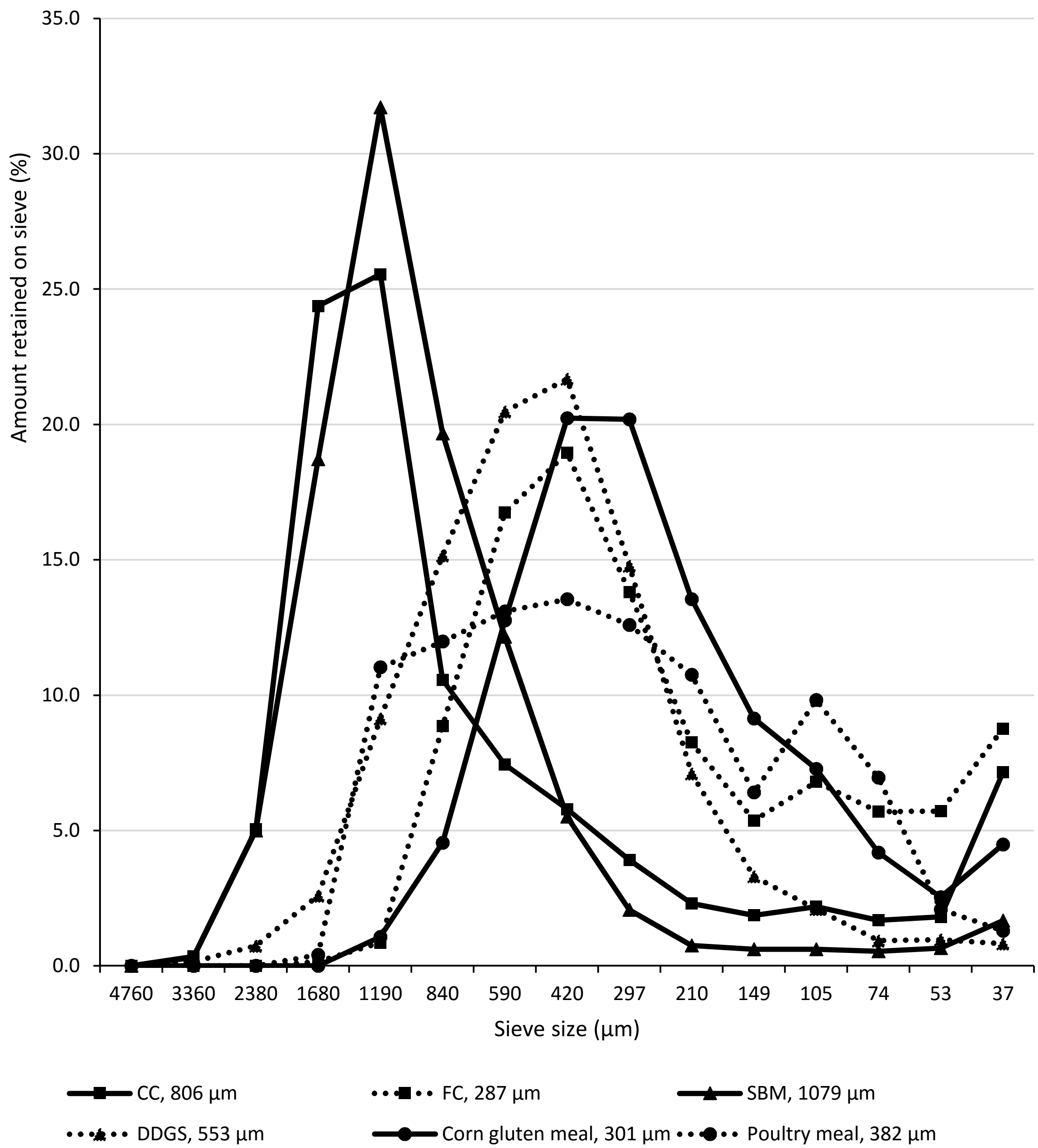

Figure II-1. Particle size distribution of ingredients. FC = fine corn, CC = coarse corn, SBM = soybean meal, DDGS = Distiller's dried grains with solubles. Actual particle size shown.

Table II-5. Pellet durability index (PDI) of pelleted grower diets as affected by main and interaction effects of percentage coarse corn of total dietary corn and percentage mixer liquid fat application

Effects			PDI	
Coarse Corn [1]	Mixer fat[2]	n[3]	Standard[4]	Modified[5]
(%)			(%)	
Main Effects				
0		16	84.4^{A}	53.7^{A}
20		16	80.2^{B}	51.4^{B}
SEM			0.146	0.270
P-value			0.001	0.001
	0.75	8	89.2^{A}	66.8^{A}
	1.50	8	88.7^{A}	68.4^{A}
	2.25	8	82.1^{B}	48.2^{B}
	3.00	8	69.3^{C}	26.9^{C}
	SEM		0.206	0.382
	P-value		0.001	0.001
Interaction Effects				
0	0.75	4	86.8^{B}	58.6^{C}
0	1.50	4	86.3^{B}	61.6^{B}
0	2.25	4	83.7^{C}	52.5^{D}
0	3.00	4	81.1^{D}	42.3^{E}
20	0.75	4	91.7^{A}	75.1^{A}
20	1.50	4	91.1^{A}	75.2^{A}
20	2.25	4	80.6^{D}	44.0^{E}
20	3.00	4	57.6^{E}	11.6^{F}
SEM			0.292	0.541
P-value			0.001	0.001

$^{A, B, C, D, E, F}$ Means within each column that possess different superscripts differ significantly ($P \leq 0.01$).

[1] Percentage coarse corn of total dietary corn in grower diets.

[2] Percentage fat that was added as mixer fat application in grower diets (Total added fat was 3.25%).

[3] Number of samples collected at the pellet mill die.

[4] Pellet Durability Index (ASABE, 2007) was determined on samples collected at the pellet mill die.

[5] Pellet Durability Index (ASABE, 2007) was determined on samples collected at the pellet mill die with 3 nuts (diameter = 19 mm).

Table II-6. Pellet durability index (PDI) of pelleted finisher diets as affected by main and interaction effects of percentage coarse corn of total dietary corn and percentage mixer liquid fat application

Effects			PDI	
Coarse Corn [1]	Mixer fat[2]	n[3]	Standard[4]	Modified[5]
(%)			(%)	
Main Effects				
0		16	86.5^{A}	62.7^{A}
30		16	80.1^{B}	57.0^{B}
SEM			0.203	0.171
P-value			0.001	0.001
	0.75	8	87.9^{A}	70.5^{A}
	1.50	8	84.8^{B}	64.0^{B}
	2.25	8	80.1^{C}	54.9^{C}
	3.00	8	80.5^{C}	50.0^{D}
	SEM		0.288	0.241
	P-value		0.001	0.001
Interaction Effects				
0	0.75	4	90.2^{A}	73.7^{A}
0	1.50	4	88.1^{B}	66.9^{B}
0	2.25	4	86.5^{BC}	59.9^{C}
0	3.00	4	81.4^{D}	50.3^{D}
30	0.75	4	85.6^{C}	67.4^{B}
30	1.50	4	81.5^{D}	61.1^{C}
30	2.25	4	79.6^{E}	50.0^{D}
30	3.00	4	73.8^{F}	49.8^{D}
SEM			0.407	0.342
P-value			0.001	0.001

$^{A, B, C, D, E, F}$ Means within each column that possess different superscripts differ significantly ($P \leq 0.01$).

[1] Percentage coarse corn of total dietary corn in finisher diets.

[2] Percentage fat that was added as mixer fat application in finisher diets (Total added fat was 3.25%).

[3] Number of samples collected at the pellet mill die.

[4] Pellet Durability Index (ASABE, 2007) was determined on samples collected at the pellet mill die.

[5] Pellet Durability Index (ASABE, 2007) was determined on samples collected at the pellet mill die with 3 nuts (diameter = 19 mm).

Table II-7. Cumulative feed intake (FI) of broiler chickens as affected by main and interaction effects of percentage coarse corn of total dietary corn and percentage mixer liquid fat application

Effects			FI				
Coarse Corn [1]	Mixer fat[2]	n[3]	14 d	28 d	35 d	42 d	49 d
(%)			(g)				
Main Effects							
0-0-0		20	656	2360	3789	5253	6882
10-20-30		20	650	2337	3761	5206	6824
SEM			8.1	21.3	30.4	42.5	58.2
P-value			0.584	0.464	0.519	0.434	0.485
	0.75	10	666	2371	3804	5287	6918
	1.50	10	649	2358	3796	5249	6868
	2.25	10	649	2334	3751	5204	6832
	3.00	10	648	2331	3750	5178	6792
	SEM		11.5	30.2	43.0	60.1	82.3
	P-value		0.664	0.747	0.722	0.598	0.734
Interaction Effects							
0-0-0	0.75	5	659	2370	3818	5299	6938
0-0-0	1.50	5	663	2350	3782	5228	6842
0-0-0	2.25	5	652	2372	3803	5276	6912
0-0-0	3.00	5	651	2347	3754	5210	6836
10-20-30	0.75	5	673	2373	3789	5274	6899
10-20-30	1.50	5	635	2365	3811	5270	6895
10-20-30	2.25	5	647	2296	3700	5132	6753
10-20-30	3.00	5	646	2315	3745	5147	6748
SEM			16.2	42.7	60.9	85.0	116.4
P-value			0.653	0.713	0.742	0.741	0.829

[1] Percentage coarse corn of total dietary corn in 0.9 kg starter, 2.7 kg grower, and 3.6 kg finisher diets fed, respectively.
[2] Percentage fat that was added as mixer fat application in grower and finisher diets (Total added fat was 3.25%).
[3] Number of replicate pens of 16 birds each.

Table II-8. Period feed intake (FI) of broiler chickens as affected by main and interaction effects of percentage coarse corn of total dietary corn and percentage mixer liquid fat application

Effects			Period FI				
Coarse Corn [1]	Mixer fat[2]	n[3]	1-14 d	15-28 d	29-35 d	36-42 d	43-49 d
(%)			(g)				
Main Effects							
0-0-0		20	656	1703	1429	1464	1629
10-20-30		20	650	1687	1424	1444	1618
SEM			8.1	15.3	11.8	17.1	20.4
P-value			0.584	0.467	0.736	0.427	0.715
	0.75	10	666	1706	1432	1483	1632
	1.50	10	649	1708	1439	1452	1620
	2.25	10	649	1685	1417	1453	1628
	3.00	10	648	1683	1419	1429	1613
	SEM		11.5	21.7	16.7	24.2	28.8
	P-value		0.664	0.762	0.758	0.482	0.968
Interaction Effects							
0-0-0	0.75	5	659	1711	1448	1481	1639
0-0-0	1.50	5	663	1687	1432	1446	1614
0-0-0	2.25	5	652	1720	1431	1474	1635
0-0-0	3.00	5	651	1696	1407	1455	1626
10-20-30	0.75	5	673	1701	1416	1485	1625
10-20-30	1.50	5	635	1730	1446	1459	1625
10-20-30	2.25	5	647	1650	1403	1432	1621
10-20-30	3.00	5	646	1670	1430	1402	1601
SEM			16.2	30.7	23.6	34.2	40.8
P-value			0.653	0.342	0.557	0.715	0.973

[1] Percentage coarse corn of total dietary corn in 0.9 kg starter, 2.7 kg grower, and 3.6 kg finisher diets fed, respectively.
[2] Percentage fat that was added as mixer fat application in grower and finisher diets (Total added fat was 3.25%).
[3] Number of replicate pens of 16 birds each.

Table II-9. Cumulative BW of broiler chickens as affected by main and interaction effects of percentage coarse corn of total dietary corn and percentage mixer liquid fat application

Effects			BW					
Coarse Corn [1]	Mixer fat[2]	n[3]	1 d	14 d	28 d	35 d	42 d	49 d
(%)			(g)					
Main Effects								
0-0-0		20	42.4	531	1716	2574	3280	4038
10-20-30		20	42.8	532	1722	2581	3278	4026
SEM			0.19	4.9	16.1	20.1	29.1	37.2
P-value			0.193	0.865	0.788	0.811	0.966	0.816
	0.75	10	42.7	528	1730	2583	3311	4073
	1.50	10	42.4	532	1734	2595	3283	4019
	2.25	10	42.5	530	1727	2595	3289	4053
	3.00	10	42.7	537	1687	2538	3234	3982
	SEM		0.27	7.0	22.9	28.5	41.2	52.7
	P-value		0.796	0.811	0.441	0.463	0.612	0.635
Interaction Effects								
0-0-0	0.75	5	42.7	532	1718	2564	3297	4072
0-0-0	1.50	5	42.1	532	1712	2582	3274	4007
0-0-0	2.25	5	42.6	532	1750	2608	3299	4069
0-0-0	3.00	5	42.2	529	1685	2543	3251	4004
10-20-30	0.75	5	42.8	525	1743	2602	3325	4073
10-20-30	1.50	5	42.7	531	1755	2607	3292	4031
10-20-30	2.25	5	42.4	527	1704	2582	3278	4038
10-20-30	3.00	5	43.2	546	1688	2534	3218	3960
SEM			0.38	9.9	32.3	40.3	58.3	74.5
P-value			0.412	0.613	0.558	0.848	0.939	0.967

[1] Percentage coarse corn of total dietary corn in 0.9 kg starter, 2.7 kg grower, and 3.6 kg finisher diets fed, respectively.
[2] Percentage fat that was added as mixer fat application in grower and finisher diets (Total added fat was 3.25%).
[3] Number of replicate pens of 16 birds each.

Table II-10. Period BW gain of broiler chickens as affected by main and interaction effects of percentage coarse corn of total dietary corn and percentage mixer liquid fat application

Effects			Period BW gain				
Coarse Corn[1]	Mixer fat[2]	n[3]	1-14 d	15-28 d	29-35 d	36-42 d	43-49 d
(%)			(g)				
Main Effects							
0-0-0		20	489	1185	858	706	758
10-20-30		20	490	1190	859	697	747
SEM			4.9	13.2	9.9	12.9	13.1
P-value			0.903	0.791	0.962	0.641	0.571
	0.75	10	486	1202	853	728	762
	1.50	10	489	1202	861	688	736
	2.25	10	487	1197	868	693	765
	3.00	10	495	1149	852	696	747
	SEM		6.9	18.7	14.0	18.2	18.5
	P-value		0.810	0.154	0.822	0.413	0.684
Interaction Effects							
0-0-0	0.75	5	489	1186	846	733	775
0-0-0	1.50	5	490	1180	870	691	734
0-0-0	2.25	5	490	1218	858	691	770
0-0-0	3.00	5	487	1156	858	708	753
10-20-30	0.75	5	482	1217	859	724	748
10-20-30	1.50	5	488	1224	852	685	739
10-20-30	2.25	5	485	1177	878	696	760
10-20-30	3.00	5	503	1142	846	684	742
SEM			9.8	26.4	19.8	25.8	26.2
P-value			0.636	0.354	0.735	0.954	0.941

[1] Percentage coarse corn of total dietary corn in 0.9 kg starter, 2.7 kg grower, and 3.6 kg finisher diets fed, respectively.
[2] Percentage fat that was added as mixer fat application in grower and finisher diets (Total added fat was 3.25%).
[3] Number of replicate pens of 16 birds each.

Table II-11. Cumulative adjusted feed conversion ratio (AdjFCR) of broiler chickens as affected by main and interaction effects of percentage coarse corn of total dietary corn and percentage mixer liquid fat application

Effects			AdjFCR[4]				
Coarse Corn [1]	Mixer fat[2]	n[3]	14 d	28 d	35 d	42 d	49 d
(%)			(g feed : g BW gain)				
Main Effects							
0-0-0		20	1.347	1.419 [a]	1.504	1.629	1.735
10-20-30		20	1.336	1.401 [b]	1.491	1.623	1.725
SEM			0.016	0.006	0.004	0.007	0.007
P-value			0.650	0.043	0.064	0.549	0.352
	0.75	10	1.379	1.412 [ab]	1.502	1.626	1.721
	1.50	10	1.333	1.401 [b]	1.492	1.626	1.733
	2.25	10	1.336	1.395 [b]	1.487	1.615	1.721
	3.00	10	1.317	1.430 [a]	1.508	1.635	1.745
	SEM		0.022	0.008	0.006	0.009	0.010
	P-value		0.282	0.036	0.117	0.570	0.335
Interaction Effects							
0-0-0	0.75	5	1.358	1.432	1.526 [a]	1.638	1.726
0-0-0	1.50	5	1.354	1.408	1.492 [bc]	1.626	1.728
0-0-0	2.25	5	1.336	1.400	1.494 [bc]	1.628	1.740
0-0-0	3.00	5	1.338	1.434	1.502 [abc]	1.622	1.746
10-20-30	0.75	5	1.400	1.392	1.478 [c]	1.614	1.716
10-20-30	1.50	5	1.312	1.394	1.492 [bc]	1.626	1.738
10-20-30	2.25	5	1.336	1.390	1.480 [c]	1.602	1.702
10-20-30	3.00	5	1.296	1.426	1.514 [ab]	1.648	1.744
SEM			0.032	0.012	0.009	0.014	0.014
P-value			0.521	0.525	0.017	0.232	0.440

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

[1] Percentage coarse corn of total dietary corn in 0.9 kg starter, 2.7 kg grower, and 3.6 kg finisher diets fed, respectively.

[2] Percentage fat that was added as mixer fat application in grower and finisher diets (Total added fat was 3.25%).

[3] Number of replicate pens of 16 birds each.

[4] AdjFCR = Adjusted feed conversion ratio was feed intake per BW gain, corrected for weight of mortality and culls.

Table II-12. Period adjusted feed conversion ratio (AdjFCR) of broiler chickens as affected by main and interaction effects of percentage coarse corn of total dietary corn and percentage mixer liquid fat application

Effects			Period AdjFCR[4]				
Coarse Corn [1]	Mixer fat[2]	n[3]	1-14 d	15-28 d	29-35 d	36-42 d	43-49 d
(%)			(g feed : g BW gain)				
Main Effects							
0-0-0		20	1.347	1.453	1.679	2.083	2.248
10-20-30		20	1.336	1.432	1.676	2.142	2.183
SEM			0.016	0.012	0.014	0.042	0.050
P-value			0.650	0.231	0.866	0.336	0.374
	0.75	10	1.379	1.427 [b]	1.682	2.069	2.150
	1.50	10	1.333	1.432 [b]	1.681	2.138	2.231
	2.25	10	1.336	1.423 [b]	1.676	2.098	2.199
	3.00	10	1.317	1.486 [a]	1.670	2.145	2.280
	SEM		0.022	0.017	0.020	0.060	0.071
	P-value		0.282	0.049	0.975	0.790	0.635
Interaction Effects							
0-0-0	0.75	5	1.358	1.466	1.710	2.022	2.116
0-0-0	1.50	5	1.354	1.432	1.662	2.120	2.214
0-0-0	2.25	5	1.336	1.432	1.694	2.132	2.262
0-0-0	3.00	5	1.338	1.480	1.650	2.058	2.398
10-20-30	0.75	5	1.400	1.388	1.654	2.116	2.184
10-20-30	1.50	5	1.312	1.432	1.700	2.156	2.248
10-20-30	2.25	5	1.336	1.414	1.658	2.064	2.136
10-20-30	3.00	5	1.296	1.492	1.690	2.232	2.162
SEM			0.032	0.024	0.029	0.085	0.101
P-value			0.521	0.277	0.250	0.553	0.419

[a, b] Means within each column that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Percentage coarse corn of total dietary corn in 0.9 kg starter, 2.7 kg grower, and 3.6 kg finisher diets fed, respectively.
[2] Percentage fat that was added as mixer fat application in grower and finisher diets (Total added fat was 3.25%).
[3] Number of replicate pens of 16 birds each.
[4] AdjFCR = Adjusted feed conversion ratio was feed intake per BW gain, corrected for weight of mortality and culls.

Table II-13. Cumulative depletion of broiler chickens as affected by main and interaction effects of percentage coarse corn of total dietary corn and percentage mixer liquid fat application

Effects			Depletion				
Coarse Corn[1]	Mixer fat[2]	n[3]	14 d	28 d	35 d	42 d	49 d
(%)			(%)				
Main Effects							
0-0-0		20	0.31	2.81	3.75	4.38	4.38
10-20-30		20	1.25	3.13	3.75	4.38	5.00
SEM			0.421	1.041	1.146	1.220	1.244
P-value			0.127	0.833	1.000	1.000	0.725
	0.75	10	0.63	2.50	2.50	3.75	4.38
	1.50	10	0.63	3.13	3.75	5.00	5.63
	2.25	10	0.00	3.13	5.63	5.63	5.63
	3.00	10	1.88	3.13	3.13	3.13	3.13
	SEM		0.596	1.472	1.621	1.725	1.759
	P-value		0.181	0.987	0.563	0.728	0.710
Interaction Effects							
0-0-0	0.75	5	1.25 [b]	5.00	5.00	5.00	5.00
0-0-0	1.50	5	0.00 [b]	1.25	2.50	5.00	5.00
0-0-0	2.25	5	0.00 [b]	3.75	6.25	6.25	6.25
0-0-0	3.00	5	0.00 [b]	1.25	1.25	1.25	1.25
10-20-30	0.75	5	0.00 [b]	0.00	0.00	2.50	3.75
10-20-30	1.50	5	1.25 [b]	5.00	5.00	5.00	6.25
10-20-30	2.25	5	0.00 [b]	2.50	5.00	5.00	5.00
10-20-30	3.00	5	3.75 [a]	5.00	5.00	5.00	5.00
SEM			0.843	2.082	2.293	2.440	2.488
P-value			0.038	0.124	0.239	0.612	0.710

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

[1] Percentage coarse corn of total dietary corn in 0.9 kg starter, 2.7 kg grower, and 3.6 kg finisher diets fed, respectively.

[2] Percentage fat that was added as mixer fat application in grower and finisher diets (Total added fat was 3.25%).

[3] Number of replicate pens of 16 birds each.

Table II-14. Carcass parts weight of broiler chickens as affected by main and interaction effects of percentage coarse corn of total dietary corn and percentage mixer liquid fat application

Effects			Carcass parts weight								
Coarse Corn [1]	Mixer fat[2]	n[3]	Live BW	Carcass Weight	Fat	Legs and Thighs	Wing	Skin	*Pectoralis major*	*Pectoralis minor*	Rack
(%)			(g)								
Main Effects											
0-0-0		60	4025	3060	55	1165	288	83	919	173	370
10-20-30		60	4013	3067	53	1169	288	85	915	178	367
SEM			11.6	10.6	1.9	6.9	3.6	2.2	8.5	3.3	3.8
P-value			0.476	0.623	0.351	0.677	0.892	0.553	0.713	0.244	0.669
	0.75	30	4007	3062	54	1167	288	81	927	177	360
	1.50	30	4036	3072	53	1161	294	91	915	174	371
	2.25	30	4034	3080	54	1171	286	82	922	184	370
	3.00	30	4000	3039	55	1168	284	83	905	167	373
	SEM		16.4	15.1	2.7	9.8	5.1	3.1	12.0	4.7	5.4
	P-value		0.297	0.238	0.934	0.914	0.544	0.104	0.603	0.092	0.334
Interaction Effects											
0-0-0	0.75	15	4006	3046	57	1162	286	80	915	174	364
0-0-0	1.50	15	4025	3067	55	1167	292	92	907	169	371
0-0-0	2.25	15	4059	3088	55	1166	293	83	935	178	366
0-0-0	3.00	15	4010	3036	53	1164	279	79	920	170	377
10-20-30	0.75	15	4008	3078	50	1172	289	82	939	180	356
10-20-30	1.50	15	4046	3078	51	1155	296	90	923	180	371
10-20-30	2.25	15	4009	3072	52	1176	279	81	909	189	373
10-20-30	3.00	15	3990	3041	58	1173	289	86	889	163	369
SEM			23.3	21.3	3.8	13.8	7.2	4.4	17.0	6.6	7.6
P-value			0.455	0.741	0.522	0.826	0.390	0.694	0.260	0.473	0.737

[1] Percentage coarse corn of total dietary corn in 0.9 kg starter, 2.7 kg grower, and 3.6 kg finisher diets fed, respectively.
[2] Percentage fat that was added as mixer fat application in grower and finisher diets (Total added fat was 3.25%).
[3] Number of replicate birds.

Table II-15. Percentage carcass parts of broiler chickens as affected by main and interaction effects of percentage coarse corn of total dietary corn and percentage mixer liquid fat application

Effects			Percentage carcass parts weight						
Coarse Corn [1]	Mixer fat[2]	n[3]	Fat	Legs and Thighs	Wing	Skin	*Pectoralis major*	*Pectoralis minor*	Rack
(%)			(%)						
Main Effects									
0-0-0		60	1.81	38.09	9.40	2.72	30.04	5.64	12.08
10-20-30		60	1.72	38.12	9.40	2.77	29.83	5.81	11.98
SEM			0.063	0.223	0.115	0.072	0.246	0.102	0.123
P-value			0.342	0.931	0.960	0.597	0.544	0.262	0.550
	0.75	30	1.76	38.13	9.39	2.65	30.23	5.78	11.76
	1.50	30	1.73	37.79	9.57	2.96	29.78	5.67	12.07
	2.25	30	1.74	38.01	9.28	2.66	29.94	5.95	12.00
	3.00	30	1.83	38.47	9.36	2.71	29.77	5.48	12.28
	SEM		0.090	0.316	0.163	0.102	0.348	0.145	0.175
	P-value		0.855	0.498	0.632	0.115	0.771	0.149	0.212
Interaction Effects									
0-0-0	0.75	15	1.88	38.18	9.38	2.62	29.98	5.71	11.95
0-0-0	1.50	15	1.79	38.06	9.53	2.99	29.58	5.50	12.09
0-0-0	2.25	15	1.79	37.74	9.49	2.68	30.29	5.76	11.86
0-0-0	3.00	15	1.76	38.36	9.22	2.59	30.31	5.61	12.43
10-20-30	0.75	15	1.63	38.09	9.40	2.68	30.49	5.86	11.57
10-20-30	1.50	15	1.66	37.52	9.62	2.94	29.99	5.85	12.05
10-20-30	2.25	15	1.69	38.28	9.07	2.64	29.59	6.14	12.15
10-20-30	3.00	15	1.90	38.57	9.50	2.84	29.24	5.36	12.13
SEM			0.127	0.447	0.231	0.145	0.493	0.205	0.247
P-value			0.495	0.660	0.490	0.697	0.283	0.397	0.533

[1] Percentage coarse corn of total dietary corn in 0.9 kg starter, 2.7 kg grower, and 3.6 kg finisher diets fed, respectively.
[2] Percentage fat that was added as mixer fat application in grower and finisher diets (Total added fat was 3.25%).
[3] Number of replicate birds.

CHAPTER III

EVALUATION OF GROUND CORN PARTICLE SIZES IN GROWER DIETS ON PELLET QUALITY, BROILER LIVE PERFORMANCE, AND PROVENTRICULUS AND GIZZARD WEIGHTS

3.1. ABSTRACT

The study was conducted to evaluate the effect of coarsely ground corn (CC) particle size on pellet quality, broiler live performance, and proventriculus and gizzard weights in male and female broilers. There were 1,920 male and female broiler chicks, 960 birds per sex, randomly assigned to 60 used wood shavings litter pens with 32 birds per pen. There were 30 male and 30 female pens. The experiment consisted of a 5 x 2 factorial arrangement of treatments consisting of 5 different average corn particle sizes (Targeted to be 400, 800, 1,200, 1,600, and 2,000 µm) that replaced 20 percent of total dietary corn in grower diets fed to two genders. Fine corn (FC) was ground with a hammermill to 316 µm (2.4 mm screen) while five different CC were ground by roller mill with appropriate roller pairs settings to 522, 848, 1,223, 1,721, and 2,378 µm, respectively. Each CC particle replaced 20 percent of total dietary corn in the basal grower diet to create the CC treatments. Pellet durability index (PDI) was determined on samples collected at the pellet die as standard and modified PDI with 3 nuts (diameter = 19 mm). Feed intake and BW were determined at 14, 21, 28, and 35 d of age and adjusted feed conversion ratio (AdjFCR) was calculated by including BW of mortality. The proventriculus and gizzard were excised and weighed at 36 d of age and organ weights relative to BW calculated. Standard PDI was not significantly different among different corn particle treatments but modified PDI was increased ($P \leq 0.05$) by the largest CC in the grower diet. Cumulative feed intake, BW, and relative weights of the proventriculus and gizzard were not affected by CC. The AdjFCR was poorest ($P \leq 0.05$) in the CC1600 treatment at 21 d but the effect was absent thereafter. As expected, cumulative feed intake and BW were greater ($P \leq 0.01$) in male broilers and AdjFCR was improved ($P \leq 0.01$) as well compared to female

broilers throughout the study. Relative gizzard weight was smaller ($P \leq 0.05$) in males compared to females. The current study implied that pellet quality was not necessarily impacted by larger CC if diets were appropriately formulated and manufactured. Further, in this study, the effect of corn particle size per se may have been modified by the large size of soybean meal (1,164 µm), so that expected effects were negated when the CC was only 11.88% of the grower diets whereas large SBM comprised 27.15%.

Keywords: broiler live performance, pellet durability index, proventriculus, gizzard

3.2. INTRODUCTION

Although it has been generally believed that fine grinding increased substrate availability for enzymatic digestion, the benefits of feeding larger particle size ingredients to poultry has received considerable attention in recent years. There has been evidence that including larger particle sizes of ingredients in feed improved the health of chickens as well as strongly influenced gastrointestinal tract (GIT) development, motility, and function (Nir et al., 1995; Amerah et al., 2007). These effects may have resulted from the positive effect of feed particle size on gizzard development. Greater gizzard development has been associated with increased grinding activity, increased gut motility, and greater digestion of nutrients. Conversely, a poorly developed gizzard has been associated with an increased feed passage rate that led to more nutrients being present in the lower GIT where they promoted microbial proliferation (Branton et al., 1987), which had a negative impact on broiler live performance.

Studies examining the effect of grain particle size in pelleted diets have produced inconsistent results. Reece et al. (1986) reported that broiler live performance was not affected by finely versus coarsely ground corn (679 and 1,289 µm) but BW and feed efficiency were improved compared to chicks fed intermediate ground corn (987 µm). Lott et al. (1992) reported that smaller feed particles (716 µm) improved BW gain and feed efficiency compared to larger particles (1,196 µm). Amerah et al. (2008) also investigated particle size of wheat and corn that varied from 284-297 and 528-890 µm and found improved BW gain with coarse corn diets compared with fine corn diets, but the effect was not evident in wheat-based diets. The nebulous terms fine, medium, and coarse particles used to describe smaller or greater particle size in most studies have hindered definitive comparison of data. In addition, the study from Chapter II showed somewhat improved AdjFCR in diets containing CC, which implied the positive effect of CC was evident in pelleted diets but broilers may require specific CC particle size. The study found evidence that coarser grinding was advantageous in terms of broiler live performance due to numerically decreased feed intake and improved feed efficiency. The improved live performance produced by CC may be due to large particles causing feed to be retained in the GIT for an increased period of digestion and absorption. In addition, coarse feed ingredients may contribute to improved live performance in broilers through improved GIT development, especially that of the gizzard (Nir et al., 1995). However, there has not been much information available concerning the relationship between gizzard size and specific corn particle size. Hence, it was not known if the aim should be to make sure the gizzard became as large as possible. Thus, it was necessary to determine a specific particle size of major ingredients to ensure an adequately developed gizzard at which broiler live performance was optimized.

3.3. MATERIALS AND METHODS

Hatching Eggs and Incubation. A total of 3,600 broiler hatching eggs were collected from 46-wk-old Ross 344 x 708 (Aviagen, Huntsville, AL) broiler breeders maintained at the research site. Preheating was carried out by moving the eggs into a room maintained at 26 to 28°C for 12 h and then bringing the Natureform setters to a set point of 38.0°C through E5 of incubation. The dry bulb temperature was then changed and gradually decreased to 37.5°C from E5 to E12, 37.4°C from E13 to E15, and 37.2°C from E16 to E18 to maintain an internal egg temperature of 37.8°C or slightly below. The incubator dry bulb temperature was independently confirmed and calibrated daily with a mercury thermometer. Relative humidity was maintained at 53% throughout incubation. The fresh air vent was initially closed until set point temperature was achieved and was at a minimum to E12 of incubation, and thereafter gradually increased to maximum at E15 of incubation.

Broiler Management. The experiment was conducted from March to May, 2014, at the North Carolina State University Chicken Educational Unit, 4108 Lake Wheeler Road, Raleigh, NC. Animal handling conformed to the Guide for Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010). Broiler chicks were hatched, feather sexed, and maintained separately by breeder pen source before and after sexing. Either 32 male or female chicks were randomly selected with two chicks coming from each of the 16 breeder pens such that breeder source and incubator position effects were equalized. Chicks were then permanently identified with neck tags, pen group weighed, and distributed onto used wood shaving litter after manual introduction to water and feed. Each pen had dimensions of 1.2 m wide by 3.6 m long with a stocking density of 7.4 birds per m^2. Each pen was equipped with one bell-type drinker and two manual tube feeders. The brooding temperature at reception of 35.0-36.1°C on the litter, which was determined by an infrared thermoscan gun, was maintained through the first night before being decreased to 31.1-32.2°C the following morning. The litter temperature was maintained from 2 to 7 d at 31.1 to 32.2°C, 8 to 14 d at 29 to 30°C, 15 to 21 d at 26 to 27°C, and at ambient temperatures thereafter. Water and broiler diets were provided for *ad libitum* consumption. Three supplemental feeder flats were used until 6 d of age, two flats to 9 d, and one flat to 12 d of age. There was 0.45 kg of broiler starter crumbles added per bird at 1 d of age. Small amounts of feed were moved out of the tube feeders onto the feeder flats once daily to 7 d of age. At 9 d of age, about 0.45 kg of broiler starter diet was added to bring the total to 0.9 kg per bird alive. The broiler feeding program was 0.9 kg/bird of starter and 2.7 kg/bird of grower diets. Feeders were shaken once per day to 14 d, and twice daily thereafter to maintain the flow of feed from tubes into pans. The lighting program schedule was 23 h of light from 1 to 7 d, 21 h of light from 8 to 21 d, and 16 h of light thereafter. House environment and birds were closely monitored and mortalities were weighed and recorded twice daily throughout the experiment.

Feed Formulation and Manufacturing. The experimental diets (Table III-1) were formulated mainly of corn and SBM. Diets were manufactured at the North Carolina State University Feed Mill Educational Unit. Fine corn (FC) was ground using a hammermill (Model 1522, Roskamp Champion, Waterloo, IA) equipped with two 2.4 mm (6/64 inch) screens. A two-pair roller mill (Model C128829, RMS, Harrisburg, SD) with different roller setting was used to produce the 5 sizes of coarse ground corn (CC). A basal mash grower diet made with fine corn (FC) was used for all treatments to reduce ingredient variation. Dry ingredients were blended in a counterpoise mixer (Model TRDB126-0604, Hayes & Stolz, Fort Worth, TX) to create the basal diet. Each experimental grower diet was produced from the basal diet by replacement of FC with 20% of each of the 5 different CC particle sizes. The mash diets were then conditioned at 82 to 85°C and pelleted with a pellet mill (Model 60-130, Bliss Industries LLC, Ponca City, OK) equipped with a 4.0 mm X 44 mm die. Pelleted diets were cooled with ambient air in a counter-flow cooler (Model VK19X19KL, Geelen Counterflow USA Inc., Orlando, Florida). The starter diet was produced as crumbles and grower diets were produced as pellets.

Data Collection. The particle size of ground ingredients and mash grower diets were determined by dry sieving according to ASAE method S319.4 (ASABE, 2012; Stark and Chewning, 2012) with the addition of sieve agitators and 0.5 g of a dispersing agent per 100 g of sample (Silicon Dioxide, SSA-58, Gilson, Lewis Center, OH). Pelleted diets were collected at the pellet die for PDI analysis. Each treatment diet was collected 4 times at evenly spaced intervals upon discharge from the pellet mill. The pellet durability index (PDI) was determined according to ASAE standard method S269.4 (ASABE, 2007). Initial BW of chicks was determined on a pen group basis and recorded on the day of placement. Thereafter, BW and feed intake were determined on a pen basis at 14, 21, 28, and 35 d of age. All dead birds were removed, weighed, and recorded twice daily. Adjusted feed conversion ratio (AdjFCR) was calculated at 14, 21, 28, and 35 d of age by including BW of all dead birds. At 36 d of age, 120 birds (2 birds per pen) were killed by cervical dislocation prior to necropsy for proventriculus and gizzard evaluation. Birds were individually weighed, the gizzard and proventriculus excised, fat trimmed, and contents removed. Both organs were weighed after rinsing and blotting dry, and expressed as both absolute weight and relative weight per 100 g BW.

Data Analysis. Pelleted samples that were collected at the pellet die served as the experimental unit for PDI data. Pen served as the experimental unit for live performance data. The experimental design was a 5 x 2 factorial randomized complete block design with 6 blocks so that each CC by gender combination was replicated with 6 pens of 32 birds each sex. Individual bird served as the experimental unit for the proventriculus and gizzard data. All data were subjected to a two-way ANOVA to determine main effects and interactions by using the GLM procedure of SAS (SAS 9.4, SAS Institute, Cary, NC, USA, 2014). Differences among treatments were determined and expressed as LS means. Statements of statistical significance were based upon a probability level of $P \leq 0.05$ unless otherwise stated.

3.4. RESULTS AND DISCUSSION

The geometric mean diameter (GMD) and geometric standard deviation (GSD) of ingredients are shown in Table III-2. The GMD of corn ground through the hammermill was determined to be 316 μm with a corresponding GSD of 2.98. The GMD of corn ground by roller mill was determined to be 522, 848, 1,223, 1,721, and 2,378 μm with a corresponding GSD of 2.51, 2.75, 2.90, 2.87, and 2.76 for the CC400, CC800, CC1200, CC1600, and CC2000 treatments, respectively. The GMD of the corn ground by roller mill was in close agreement with the targeted particle size with the exception of the 2,000 μm lot. A comparison of the particle size distributions of ingredients is shown in Figure III-1, which confirmed that the particle size distributions of the CC and FC were not identical. Table III-3 depicts the details of GMD, GSD, and particle size distributions following dry sieving according to ASAE method S319.4.

The GMD and GSD of basal and mash grower diets are shown in Table III-4. The GMD of basal and mash grower diets was determined to be 524, 549, 593, 621, 622, and 676 µm with a corresponding GSD of 2.89, 2.70, 2.70, 2.69, 2.94, and 2.76 for the basal and CC400, CC800, CC1200, CC1600, and CC2000 treatments, respectively. A graphic comparison of the particle size distributions of basal and mash grower diets is shown in Figure III-2, which demonstrated that the particle size distributions of the final mixed mash grower diets were nearly identical. Table III-5 shows the comparisons of the particle size distributions of the basal and mash diets after dry sieving. The differences in particle size distribution, notably in the proportion of coarse particles (1,190 µm and over) were between 24.3-31.9% across all mash grower diets.

The main effects of 20% CC of total dietary corn with different corn particle size in grower diets on pellet durability index (PDI) is shown in Table III-6. There were no differences evidenced by the standard PDI but the modified PDI was interestingly improved by approximately 3% by the largest corn particle size as compared to the diet that contained the smallest particle size ($P \leq 0.05$). This improvement was in agreement with Reece et al. (1986) who reported improved pellet quality as particle size increased in contrast to the traditional theory that improved pellet quality was associated with smaller particle size grains (Wondra et al., 1995). The evidence demonstrated the possibility that with appropriate formulation and manufacture that good pellet quality could be produced even with large feed ingredient particles. The improved modified PDI was probably aided by the addition of pellet binder (Ameri-Bond 2X®, LignoTech USA, Inc, South Rothschild, Wisconsin) and wheat, which have been well known to be ingredients with positive binding properties (Winowiski, 1988).

The main and interaction effects of different CC particle size and gender on cumulative feed intake are shown in Table III-7. As expected, male broilers consumed greater amounts of feed ($P \leq 0.01$) throughout the experiment. There was no main effect of different CC particle size and no interaction effect. Table III-8 shows period feed intake where males consumed greater amounts of feed ($P \leq 0.01$) during every age period. There was poorer period feed intake from 22-28 d ($P \leq 0.05$) in broilers fed CC2000 treatment compared to CC1200 and CC1600 treatments with the CC400 and CC800 treatments intermediate. It seemed that male broilers responded negatively to very large CC particle size (CC2000 treatment) from 29-35 d ($P \leq 0.05$) as evidenced by reduced feed intake.

The main and interaction effects of different CC particle size and gender on BW are shown in Table III-9. Male broilers exhibited greater BW compared to females ($P \leq 0.01$), as expected. There was no main effect of different CC particle size and no interaction effect. With respect to period BW gain shown in Table III-10, male broilers were heavier than females ($P \leq 0.01$), as expected. There was an interaction created by decreased period BW gain from 29-35 d ($P \leq 0.05$) in male broilers fed CC1600 and CC2000 treatments, which emphasized that male broilers responded negatively to large CC particle sizes when females did not. It was then questioned that male broiler performance may be negatively triggered by CC larger than 1,600 μm.

The main and interaction effects of different CC particle size and gender on cumulative AdjFCR are shown in Table III-11. The AdjFCR at 21 d was poorest in broilers fed CC1600 treatment ($P \leq 0.05$) compared to all others but the effect disappeared thereafter. According to gender, better AdjFCR was observed in male broilers ($P \leq 0.01$), as expected. Improved period AdjFCR was observed in male broilers ($P \leq 0.01$) as shown in Table III-12. However, there were no main effect of different CC particle size or interaction effects on period AdjFCR.

The main and interaction effects of different CC particle size and gender on cumulative depletion are shown in Table III-13. There were no significant main or interaction effects on depletion.

Absolute and relative weights of proventriculus and gizzard at 36 d of age are shown in Table III-14. Relative proventriculus and gizzard weights were not affected by CC treatments. Based on our knowledge, weight of proventriculus generally decreased with increasing size of CC whereas weight of gizzard increased. We hypothesized these results that in the absence of CC, birds may have instinctively consumed litter and particle size of solvent extracted SBM observed larger than expectation (1,164 μm), which these factors masked the effect of 20% CC replacement of varying sizes on GIT development as evidence by the absence of relative proventriculus and gizzard weight differences. Male broilers had smaller relative weights of gizzard ($P \leq 0.05$) but greater absolute weights of proventriculus and gizzard. Smaller relative gizzard weight in male broilers may account for better feed efficiency probably due to their being genetically selected for more efficient musculature that required less energy for gizzard grinding activity that left increased energy available for growth. Interestingly, a larger absolute and relative weight of proventriculus was observed in male broilers fed CC400 treatment ($P \leq 0.05$). This implied that male broilers responded to the CC400 treatment by increasing enzymatic secretion in the proventriculus to compensate for rapid passage rate.

Overall, the main effect of different CC particle sizes was not clearly evident through improved growth performance. However, numerically improved period AdjFCR from 29-35 d of age in broilers fed CC800 treatment implied that the effect of CC existed in these pelleted diets and was linked to the length of the growing period. At this point, it should be obvious that GMD of corn particles may not be the only factor that influenced intestinal organ development, which was illustrated by the absence of difference in relative proventriculus and gizzard weights due to CC, which therefore prevented improved live performance. The particle size distribution and GMD of mash grower diets in Table III-5 detailed the diet containing CC1600 treatment produced a GMD mash diet of 622 μm and the diet containing CC2000 treatment produced a GMD mash diet of 676 μm, which were nearly identical. This was unexpected. In addition, the particle size distribution of the diet containing CC1600 treatment exhibited almost the same proportion of retained coarse particles (1,190 μm and over, 31.98%) as the diet containing CC2000 treatment (1,190 μm and over, 31.67%). It was brought to our attention that large corn particles retained above 1,190 μm and large particle size of solvent extracted SBM observed may mask the effect of 20% CC replacement of varying sizes on GIT development. There was limited data concerning corn and SBM particle size on internal organs and live performance. Therefore, the importance of the particle size of both corn and SBM was considered to be an important point to be examined during the next study.

The main effect of sex influenced growth performance and feed efficiency, as expected. Male broilers grew faster, consumed more feed, and exhibited better AdjFCR compared to female broilers. Genetic selection has been the primary contributor to improved broiler live performance (Havenstein et al., 2003) and males have typically performed better than females in terms of feed intake, growth rate, and feed efficiency (Kidd et al., 2004; Corzo et al., 2005). Greater absolute weights of proventriculus and gizzard were observed in males, which was in proportion to BW. However, smaller relative weight of gizzard in males compared to females was not previously reported.

Nevertheless, the interaction effects of decreased period feed intake from 29-35 d in male broilers fed CC2000 treatment, decreased BW gain from 29-35d in male broilers fed CC1600 and CC2000 treatments, and greater relative weight of the proventriculus in male broilers fed CC400 treatment suggested that male broilers may be more sensitive than females to different CC particles. These data implied the range of particles should be about 400-1,600 μm in order to have a positive effect on GIT development and live performance.

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Table III-1. The composition of broiler starter diet and grower diets with 20 percent coarse corn (CC) of total dietary corn

	Target particle size of CC ground by roller mill[1]					
	Starter	Grower				
Ingredients		CC400[1]	CC800[1]	CC1200[1]	CC1600[1]	CC2000[1]
	(%)					
Fine corn (hammermill)	54.08	47.50	47.50	47.50	47.50	47.50
Coarse corn	---	11.88	11.88	11.88	11.88	11.88
SBM (48% CP)	34.76	27.15	27.15	27.15	27.15	27.15
Wheat	2.50	5.00	5.00	5.00	5.00	5.00
Poultry by-product meal (53% CP)	2.50	2.50	2.50	2.50	2.50	2.50
Poultry fat	2.00	2.00	2.00	2.00	2.00	2.00
Dicalcium phosphate (18.5% P)	1.93	1.36	1.36	1.36	1.36	1.36
Limestone	0.77	0.63	0.63	0.63	0.63	0.63
Salt	0.46	0.47	0.47	0.47	0.47	0.47
DL-Methionine	0.24	0.22	0.22	0.22	0.22	0.22
L-Lysine-HCL (78%)	0.11	0.16	0.16	0.16	0.16	0.16
L-Threonine	0.09	0.09	0.09	0.09	0.09	0.09
Choline chloride (60%)	0.20	0.20	0.20	0.20	0.20	0.20
Mineral premix [1]	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin premix [2]	0.05	0.05	0.05	0.05	0.05	0.05
Selenium premix [3]	0.05	0.05	0.05	0.05	0.05	0.05
Coccidiostat [4]	0.05	0.05	0.05	0.05	0.05	0.05
Pellet binder (Ameri-Bond 2X®)	---	0.50	0.50	0.50	0.50	0.50
Calculated nutrients						
Protein	23.00	20.00	20.00	20.00	20.00	20.00
Calcium	1.00	0.80	0.80	0.80	0.80	0.80
Available phosphorus	0.50	0.40	0.40	0.40	0.40	0.40
Total lysine	1.31	1.14	1.14	1.14	1.14	1.14
Total methionine	0.59	0.53	0.53	0.53	0.53	0.53
Total threonine	0.86	0.75	0.75	0.75	0.75	0.75
Total methionine + cysteine	0.95	0.85	0.85	0.85	0.85	0.85
Sodium	0.20	0.20	0.20	0.20	0.20	0.20
ME, kcal/g	2.89	2.96	2.96	2.96	2.96	2.96
Analyzed nutrients						
Protein	19.56	21.25	20.88	19.81	20.11	20.20
Fat	3.80	4.08	4.14	3.92	4.27	3.60
Fiber	2.60	2.60	2.70	2.50	2.80	2.70
Ash	6.04	5.54	5.64	5.33	5.49	5.50
Moisture	13.20	13.50	13.35	13.30	13.61	13.34

[1] Mineral premix supplied the following per kg of feed: Mn 108 mg, Zn 108 mg, Fe 72.6 mg, Cu 9 mg, I 2.2 mg, and Co 2.2 mg.

[2] Vitamin premix supplied the following per kg of feed: vitamin A 6608 IU, vitamin D_3 1982 IU; vitamin E 33 IU, vitamin B_6 3.9 mg, vitamin B_{12} 0.02 mg, biotin 0.13 mg, niacin 55 mg, thiamine 1.9 mg, riboflavin 6.6 mg, menadione (K_3) 1.9 mg, d-pantothenic acid 11 mg, and folic acid 1.1 mg.

[3] Selenium premix supplied Se at 0.3 mg per kg of feed.

[4] Coccidiostat supplied monensin sodium at 99 mg per kg of feed.

Table III-2. Mean diameter particle size of ingredients

Ingredients and target particle size	Dgw[1]	Sgw[2]
	(µm)	
Fine corn	316	2.98
Coarse corn (400 µm)	522	2.51
Coarse corn (800 µm)	848	2.75
Coarse corn (1200 µm)	1223	2.90
Coarse corn (1600 µm)	1721	2.87
Coarse corn (2000 µm)	2378	2.76
Soybean meal	1164	2.40
Poultry byproduct meal	364	2.44
Wheat	269	3.20

[1] Geometric mean diameter was determined by dry sieving according to ASAE method S319.4 with the addition of sieve agitators and 0.5 g of a dispersing agent per 100 g of sample (ASABE, 2012; Stark and Chewning, 2012).
[2] Geometric standard deviation of mean particle size.

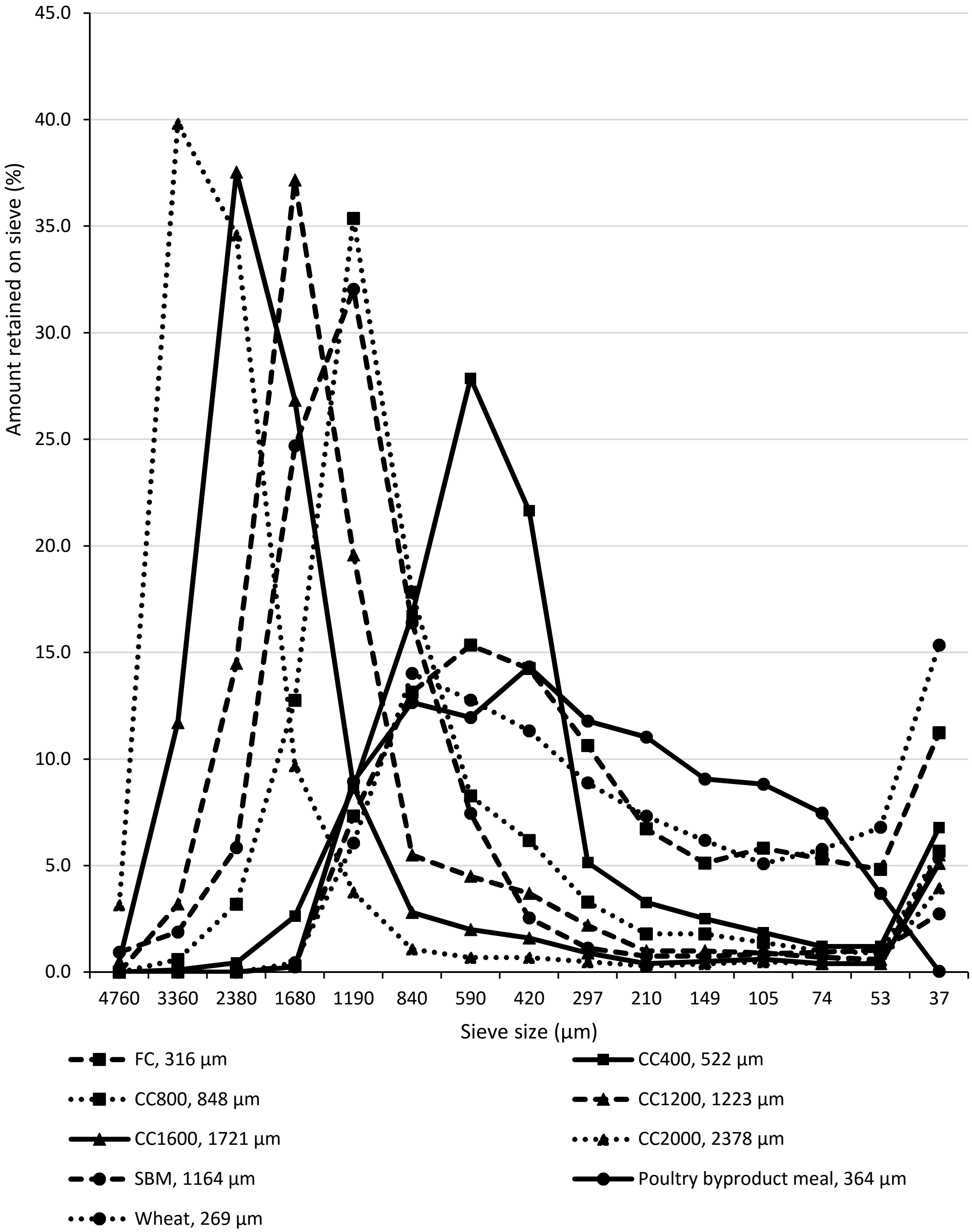

Figure III-1. Particle size distribution of ingredients. FC = fine corn, CC = coarsely ground corn, SBM = soybean meal. Actual particle size shown.

Table III-3. Percentage particle size distribution and mean diameter particle size of corn ingredients after grinding

		Target particle size of CC ground by hammermill and roller mill					
U.S. Sieve	Size	FC	CC400	CC800	CC1200	CC1600	CC2000
	(μm)	(%)					
4	4760	0.00	0.00	0.00	0.00	0.50	3.16
6	3360	0.00	0.11	0.60	3.20	11.71	39.82
8	2380	0.00	0.44	3.19	14.49	37.54	34.58
12	1680	0.30	2.62	12.75	37.16	26.83	9.68
16	1190	7.32	8.63	35.36	19.58	8.71	3.75
20	840	13.14	16.72	17.83	5.49	2.80	1.09
30	590	15.35	27.87	8.27	4.50	2.00	0.69
40	420	14.24	21.64	6.18	3.70	1.60	0.69
50	297	10.63	5.14	3.29	2.20	0.90	0.49
70	210	6.72	3.28	1.79	1.00	0.40	0.30
100	149	5.12	2.51	1.79	1.00	0.50	0.40
140	105	5.82	1.86	1.39	0.90	0.60	0.49
200	74	5.32	1.20	1.00	0.70	0.40	0.40
270	53	4.81	1.20	0.90	0.60	0.40	0.49
Pan	37	11.23	6.78	5.68	5.49	5.11	3.95
Dgw[1]		316	522	848	1223	1721	2378
Sgw[2]		2.98	2.51	2.75	2.90	2.87	2.76

[1] Geometric mean diameter was determined by dry sieving according to ASAE method S319.4 with the addition of sieve agitators and 0.5 g of a dispersing agent per 100 g of sample (ASABE, 2012; Stark and Chewning, 2012).
[2] Geometric standard deviation of mean particle size.

Table III-4. Mean diameter particle size of mash grower diets

Diets and treatment particle size of CC diets	Dgw[1]	Sgw[2]
	(µm)	
Basal	524	2.89
CC400	549	2.70
CC800	593	2.70
CC1200	621	2.69
CC1600	622	2.94
CC2000	676	2.76

[1] Geometric mean diameter was determined by dry sieving according to ASAE method S319.4 with the addition of sieve agitators and 0.5 g of a dispersing agent per 100 g of sample (ASABE, 2012; Stark and Chewning, 2012).
[2] Geometric standard deviation of mean particle size.

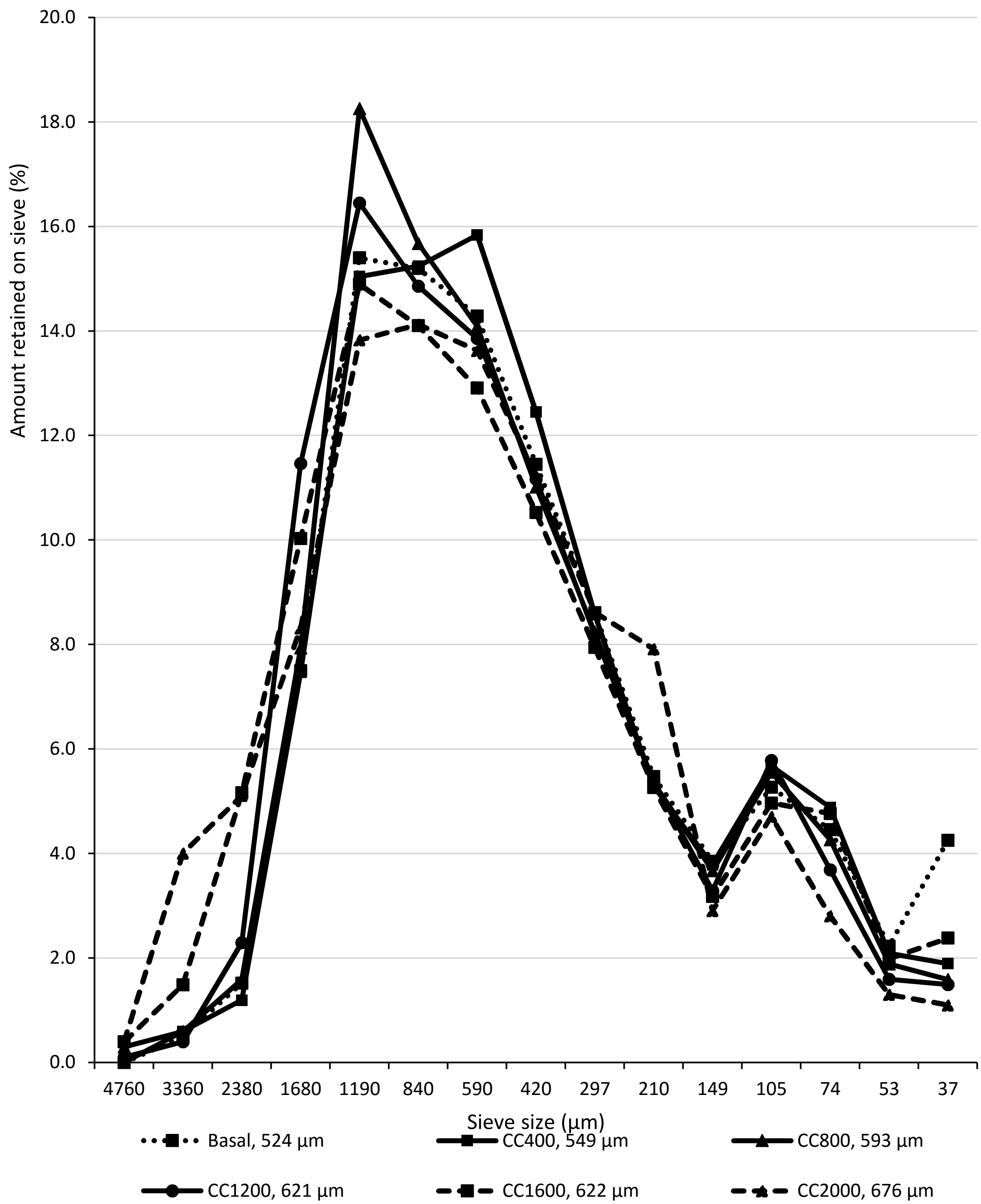

Figure III-2. Particle size distribution of mash grower diets. CC = coarsely ground corn. Actual particle size shown.

Table III-5. Percentage particle size distribution and mean diameter particle size of mash grower diets with coarsely ground corn (CC) inclusion

		Basal and treatment particle size of CC diets ground by and roller mill					
U.S. Sieve	Size	Basal	CC400	CC800	CC1200	CC1600	CC2000
	(µm)	(%)					
4	4760	0.00	0.00	0.30	0.10	0.40	0.40
6	3360	0.51	0.60	0.60	0.40	1.49	4.01
8	2380	1.52	1.20	1.59	2.29	5.16	5.11
12	1680	7.50	7.47	7.94	11.47	10.03	8.32
16	1190	15.40	15.04	18.25	16.45	14.90	13.83
20	840	15.20	15.24	15.67	14.86	14.10	14.13
30	590	14.29	15.84	14.09	13.86	12.91	13.63
40	420	11.45	12.45	11.01	11.17	10.53	11.22
50	297	8.61	8.57	8.23	8.18	7.94	8.62
70	210	5.47	5.28	5.36	5.38	5.26	7.92
100	149	3.85	3.78	3.67	3.29	3.18	2.91
140	105	5.27	5.68	5.56	5.78	4.97	4.71
200	74	4.46	4.88	4.27	3.69	4.77	4.71
270	53	2.23	2.09	1.88	1.60	1.99	1.30
Pan	37	4.26	1.89	1.59	1.50	2.38	1.10
Dgw[1]		524	549	593	621	622	676
Sgw[2]		2.89	2.70	2.70	2.69	2.94	2.76

[1] Geometric mean diameter was determined by dry sieving according to ASAE method S319.4 with the addition of sieve agitators and 0.5 g of a dispersing agent per 100 g of sample (ASABE, 2012; Stark and Chewning, 2012).
[2] Geometric standard deviation of mean particle size.

Table III-6. Pellet durability index (PDI) of pelleted grower diets as affected by 20 percent coarsely ground corn (CC) by roller mill of total dietary corn

Target CC particle size[1]	n[2]	PDI	
		Standard[3]	Modified[4]
(μm)		(%)	
400	4	90.7	68.4[b]
800	4	90.5	68.3[b]
1200	4	90.8	68.2[b]
1600	4	90.7	69.9[ab]
2000	4	90.7	71.3[a]
SEM		0.51	0.72
P-value		0.995	0.029

[a, b] Means within each column that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Particle size of corn that comprised 20 percent of total dietary corn in grower diets.
[2] Number of samples collected at the pellet mill die.
[3] Pellet Durability Index (ASABE, 2007) was determined on samples collected at the pellet mill die.
[4] Pellet Durability Index (ASABE, 2007) was determined on samples collected at the pellet mill die with 3 nuts (diameter = 19 mm).

Table III-7. Cumulative feed intake (FI) of broiler chickens as affected by main and interaction effects of different coarsely ground corn (CC) particle size and gender

Effects			Feed Intake and d of age			
Target CC particle size[1]	Gender[2]	n[3]	14 d	21 d	28 d	35 d
(µm)			(g)			
Main Effects						
400		12	635	1388	2474	3516
800		12	639	1389	2481	3533
1200		12	638	1395	2495	3552
1600		12	645	1401	2507	3552
2000		12	636	1380	2455	3492
SEM			4.4	8.0	14.0	17.3
P-value			0.528	0.442	0.121	0.086
	F	30	627^{B}	1340^{B}	2340^{B}	3289^{B}
	M	30	651^{A}	1441^{A}	2625^{A}	3769^{A}
	SEM		2.8	5.0	8.9	10.9
	P-value		0.001	0.001	0.001	0.001
Interaction Effects						
400	F	6	630	1348	2346	3284
800	F	6	629	1338	2330	3274
1200	F	6	626	1343	2357	3327
1600	F	6	633	1350	2354	3297
2000	F	6	614	1321	2314	3265
400	M	6	639	1428	2603	3747
800	M	6	650	1440	2632	3793
1200	M	6	650	1447	2633	3778
1600	M	6	657	1452	2659	3806
2000	M	6	658	1439	2597	3719
SEM			6.2	11.3	19.9	24.5
P-value			0.127	0.578	0.754	0.489

[A, B] Means within each column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Particle size of corn that comprised 20 percent of total dietary corn in grower diets.
[2] Gender consisted of separate pens of females (F) and males (M).
[3] Number of replicate pens of 32 birds each.

Table III-8. Period feed intake (FI) of broiler chickens as affected by main and interaction effects of different coarsely ground corn (CC) particle size and gender

Effects			Period Feed Intake and d of age			
Target CC particle size[1]	Gender[2]	n[3]	1-14 d	15-21 d	22-28 d	29-35 d
(µm)			(g)			
Main Effects						
400		12	635	753	1086^{ab}	1041
800		12	639	749	1092^{ab}	1051
1200		12	638	756	1100^{a}	1057
1600		12	645	755	1105^{a}	1045
2000		12	636	744	1075^{b}	1036
SEM			4.4	4.9	6.8	6.2
P-value			0.528	0.357	0.029	0.150
	F	30	627^{B}	713^{B}	1000^{B}	948^{B}
	M	30	651^{A}	790^{A}	1183^{A}	1143^{A}
	SEM		2.8	3.1	4.3	3.9
	P-value		0.001	0.001	0.001	0.001
Interaction Effects						
400	F	6	630	718	997	938^{c}
800	F	6	629	709	992	943^{c}
1200	F	6	626	716	1014	969^{c}
1600	F	6	633	716	1004	942^{c}
2000	F	6	614	707	992	950^{c}
400	M	6	639	788	1175	1143^{ab}
800	M	6	650	790	1192	1160^{a}
1200	M	6	650	797	1185	1144^{ab}
1600	M	6	657	795	1206	1147^{a}
2000	M	6	658	780	1158	1122^{b}
SEM			6.2	6.9	9.6	8.7
P-value			0.127	0.916	0.226	0.045

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

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

[1] Particle size of corn that comprised 20 percent of total dietary corn in grower diets.

[2] Gender consisted of separate pens of females (F) and males (M).

[3] Number of replicate pens of 32 birds each.

Table III-9. Cumulative BW of broiler chickens as affected by main and interaction effects of different coarsely ground corn (CC) particle size and gender

Effects			BW and d of age				
Target CC particle size[1]	Gender[2]	n[3]	1 d	14 d	21 d	28 d	35 d
(μm)			(g)				
Main Effects							
400		12	45.2	543	1052	1737	2308
800		12	45.1	545	1047	1737	2308
1200		12	45.4	545	1048	1742	2316
1600		12	45.3	543	1042	1743	2294
2000		12	45.2	541	1038	1717	2279
SEM			0.14	4.1	5.2	8.8	10.0
P-value			0.533	0.932	0.349	0.244	0.100
	F	30	45.2	528^{B}	997^{B}	1605^{B}	2102^{B}
	M	30	45.3	559^{A}	1094^{A}	1865^{A}	2500^{A}
	SEM		0.09	2.6	3.3	5.6	6.3
	P-value		0.395	0.001	0.001	0.001	0.001
Interaction Effects							
400	F	6	45.2	533	1006	1612	2104
800	F	6	45.0	529	994	1602	2091
1200	F	6	45.2	529	999	1618	2127
1600	F	6	45.4	529	996	1600	2089
2000	F	6	45.2	521	990	1590	2100
400	M	6	45.2	553	1099	1861	2512
800	M	6	45.2	561	1100	1872	2524
1200	M	6	45.6	561	1098	1866	2505
1600	M	6	45.2	558	1087	1885	2500
2000	M	6	45.2	560	1087	1843	2458
SEM			0.20	5.8	7.4	12.5	14.2
P-value			0.583	0.618	0.874	0.536	0.085

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

[1] Particle size of corn that comprised 20 percent of total dietary corn in grower diets.

[2] Gender consisted of separate pens of females (F) and males (M).

[3] Number of replicate pens of 32 birds each.

Table III-10. Period BW gain of broiler chickens as affected by main and interaction effects of different coarsely ground corn (CC) particle size and gender

Effects			Period BW gain and d of age			
Target CC particle size[1]	Gender[2]	n[3]	1-14 d	15-21 d	22-28 d	29-35 d
(µm)			(g)			
Main Effects						
400		12	498	509	684	571
800		12	500	502	689	570
1200		12	500	503	693	574
1600		12	498	498	700	551
2000		12	495	497	678	562
SEM			4.0	3.3	5.5	7.6
P-value			0.932	0.117	0.066	0.241
	F	30	483^{B}	468^{B}	607^{B}	497^{B}
	M	30	513^{A}	535^{A}	771^{A}	634^{A}
	SEM		2.5	2.1	3.5	4.8
	P-value		0.001	0.001	0.001	0.001
Interaction Effects						
400	F	6	488	472	606	491^{c}
800	F	6	484	465	608	488^{c}
1200	F	6	484	469	618	508^{c}
1600	F	6	484	466	604	488^{c}
2000	F	6	476	468	600	509^{c}
400	M	6	508	546	761	651^{a}
800	M	6	516	539	771	652^{a}
1200	M	6	516	536	767	639^{ab}
1600	M	6	512	529	797	615^{b}
2000	M	6	515	526	756	615^{b}
SEM			5.7	4.7	7.8	10.7
P-value			0.614	0.385	0.057	0.050

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

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

[1] Particle size of corn that comprised 20 percent of total dietary corn in grower diets.

[2] Gender consisted of separate pens of females (F) and males (M).

[3] Number of replicate pens of 32 birds each.

Table III-11. Cumulative adjusted feed conversion ratio (AdjFCR) of broiler chickens as affected by main and interaction effects of different coarsely ground corn (CC) particle size and gender

Effects			AdjFCR and d of age			
Target CC particle size[1]	Gender[2]	n[3]	14 d	21 d	28 d	35 d
(µm)			(g feed : g BW gain)			
Main Effects						
400		12	1.281	1.388^{b}	1.477	1.585
800		12	1.283	1.393^{b}	1.478	1.575
1200		12	1.279	1.396^{b}	1.480	1.584
1600		12	1.300	1.411^{a}	1.493	1.593
2000		12	1.283	1.394^{b}	1.482	1.588
SEM			0.006	0.004	0.004	0.004
P-value			0.196	0.022	0.148	0.113
	F	30	1.300^{A}	1.414^{A}	1.509^{A}	1.615^{A}
	M	30	1.270^{B}	1.378^{B}	1.455^{B}	1.555^{B}
	SEM		0.004	0.003	0.003	0.003
	P-value		0.001	0.001	0.001	0.001
Interaction Effects						
400	F	6	1.298	1.412	1.507	1.615
800	F	6	1.305	1.417	1.508	1.612
1200	F	6	1.297	1.417	1.505	1.608
1600	F	6	1.312	1.423	1.522	1.622
2000	F	6	1.290	1.403	1.502	1.620
400	M	6	1.263	1.365	1.447	1.555
800	M	6	1.260	1.368	1.448	1.538
1200	M	6	1.262	1.375	1.455	1.560
1600	M	6	1.288	1.398	1.465	1.565
2000	M	6	1.277	1.385	1.462	1.557
SEM			0.009	0.006	0.006	0.006
P-value			0.516	0.115	0.569	0.462

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

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

[1] Particle size of corn that comprised 20 percent of total dietary corn in grower diets.

[2] Gender consisted of separate pens of females (F) and males (M).

[3] Number of replicate pens of 32 birds each.

Table III-12. Period adjusted feed conversion ratio (AdjFCR) of broiler chickens as affected by main and interaction effects of different coarsely ground corn (CC) particle size and gender

Effects			Period AdjFCR and d of age			
Target CC particle size[1]	Gender[2]	n[3]	1-14 d	15-21 d	22-28 d	29-35 d
(µm)			(g feed : g BW gain)			
Main Effects						
400		12	1.281	1.495	1.612	1.941
800		12	1.283	1.505	1.611	1.864
1200		12	1.279	1.513	1.609	1.913
1600		12	1.300	1.523	1.616	1.919
2000		12	1.283	1.504	1.621	1.925
SEM			0.006	0.007	0.010	0.018
P-value			0.196	0.138	0.935	0.054
	F	30	1.300^{A}	1.532^{A}	1.662^{A}	1.966^{A}
	M	30	1.270^{B}	1.484^{B}	1.566^{B}	1.859^{B}
	SEM		0.004	0.004	0.006	0.011
	P-value		0.001	0.001	0.001	0.001
Interaction Effects						
400	F	6	1.298	1.532	1.660	1.985
800	F	6	1.305	1.532	1.662	1.933
1200	F	6	1.297	1.540	1.648	1.940
1600	F	6	1.312	1.542	1.673	1.958
2000	F	6	1.290	1.517	1.665	2.012
400	M	6	1.263	1.458	1.563	1.897
800	M	6	1.260	1.478	1.560	1.795
1200	M	6	1.262	1.487	1.570	1.885
1600	M	6	1.288	1.503	1.558	1.880
2000	M	6	1.277	1.492	1.577	1.838
SEM			0.009	0.010	0.014	0.025
P-value			0.516	0.248	0.778	0.156

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

[1] Particle size of corn that comprised 20 percent of total dietary corn in grower diets.

[2] Gender consisted of separate pens of females (F) and males (M).

[3] Number of replicate pens of 32 birds each.

Table III-13. Cumulative depletion of broiler chickens as affected by main and interaction effects of different coarsely ground corn (CC) particle size and gender

Effects			Depletion and d of age			
Target CC particle size[1]	Gender[2]	n[3]	14 d	21 d	28 d	35 d
(µm)			(%)			
Main Effects						
400		12	1.04	1.83	3.39	5.21
800		12	0.78	1.57	2.87	3.39
1200		12	0.78	1.30	3.13	5.47
1600		12	1.30	1.83	3.65	4.43
2000		12	0.00	0.52	2.35	3.65
SEM			0.376	0.529	0.984	1.165
P-value			0.171	0.395	0.902	0.648
	F	30	0.73	1.15	2.40	3.44
	M	30	0.83	1.67	3.75	5.42
	SEM		0.238	0.334	0.622	0.737
	P-value		0.758	0.276	0.131	0.064
Interaction Effects						
400	F	6	1.04	1.04	2.61	4.17
800	F	6	1.04	1.57	3.13	3.13
1200	F	6	1.04	2.09	3.13	4.69
1600	F	6	0.52	1.04	2.09	2.61
2000	F	6	0.00	0.00	1.04	2.61
400	M	6	1.04	2.61	4.17	6.25
800	M	6	0.52	1.57	2.61	3.65
1200	M	6	0.52	0.52	3.13	6.25
1600	M	6	2.08	2.61	5.21	6.25
2000	M	6	0.00	1.04	3.65	4.69
SEM			0.532	0.748	1.391	1.648
P-value			0.286	0.197	0.628	0.917

[1] Particle size of corn that comprised 20 percent of total dietary corn in grower diets.
[2] Gender consisted of separate pens of females (F) and males (M).
[3] Number of replicate pens of 32 birds each.

Table III-14. Absolute and relative weights of the proventriculus and gizzard of broiler chickens at 36 d of age as affected by main and interaction effects of different coarsely ground corn (CC) particle size and gender

Effects			Proventriculus		Gizzard	
Target CC particle size[1]	Gender[2]	n[3]	Absolute	Relative	Absolute	Relative
(µm)			(g)	(g/100 g BW)	(g)	(g/100 g BW)
Main Effects						
400		24	8.18[a]	0.34	22.60	0.96
800		24	6.92[b]	0.30	20.68	0.88
1200		24	7.48[ab]	0.32	22.69	0.98
1600		24	7.07[b]	0.30	21.91	0.95
2000		24	6.94[b]	0.30	22.52	0.96
SEM			0.332	0.013	0.628	0.026
P-value			0.044	0.062	0.135	0.107
	F	60	6.58[B]	0.31	20.84[B]	0.97[a]
	M	60	8.06[A]	0.32	23.32[A]	0.92[b]
	SEM		0.210	0.008	0.397	0.016
	P-value		0.001	0.378	0.001	0.026
Interaction Effects						
400	F	12	6.60[c]	0.31[b]	21.36	1.00
800	F	12	6.39[c]	0.29[b]	19.43	0.90
1200	F	12	6.80[c]	0.32[b]	21.60	1.02
1600	F	12	6.22[c]	0.29[b]	20.59	0.98
2000	F	12	6.89[bc]	0.32[b]	21.22	0.99
400	M	12	9.76[a]	0.38[a]	23.83	0.93
800	M	12	7.45[b]	0.30[b]	21.92	0.87
1200	M	12	8.16[b]	0.32[b]	23.79	0.94
1600	M	12	7.92[b]	0.31[b]	23.22	0.92
2000	M	12	7.00[b]	0.28[b]	23.81	0.94
SEM			0.470	0.019	0.888	0.037
P-value			0.030	0.048	0.999	0.967

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

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

[1] Particle size of corn that comprised 20 percent of total dietary corn in grower diets.

[2] Gender consisted of separate pens of females (F) and males (M).

[3] Number of chickens with 2 from each pen.

CHAPTER IV

EVALUATION OF GROUND CORN PARTICLE SIZES, CORN PARTICLE DISTRIBUTIONS, AND EXPELLER-EXTRACTED SOYBEAN MEAL PARTICLE SIZES IN GROWER DIETS ON PELLET QUALITY, BROILER LIVE PERFORMANCE, AND PROVENTRICULUS AND GIZZARD WEIGHTS

4.1. ABSTRACT

The effects of coarsely ground corn (CC) particle size and distribution on pellet quality, broiler live performance, and proventriculus and gizzard weights were determined. The total of 2,304 male broilers were randomly assigned to 72 pens with 32 birds per used wood shaving litter floor pen. The experiment comprised a 4 x 2 factorial arrangement of treatments consisting of 4 different average corn particle sizes (Targeted to be 400, 800, 1,200, and 1,600 μm) that replaced 50% of total dietary corn in the grower diets and two expeller-extracted soybean meal (ESBM) particle sizes (fine versus coarse). Fine expeller-extracted soybean meal (FESBM) was ground with a hammermill equipped with 2.4 mm screens to 314 μm, whereas fine corn (FC) was ground by hammermill to 349 μm and three different coarse corn (CC) were ground by roller mill with different roller pair setting to 798, 1,276, and 1,602 μm, respectively. Each corn particle treatment replaced 50% of total dietary corn in grower diets to create the corn particle treatments. Pellet durability index (PDI) was determined on samples collected at the pellet die as standard and modified PDI with 3 nuts (diameter = 19 mm). Feed intake and BW were determined at 15, 22, 29, 36, and 43 d of age and adjusted feed conversion ratio (AdjFCR) was calculated by including BW of mortality. The proventriculus and gizzard were excised and weighed at 45 d of age and organ weights were expressed on both an absolute and relative to BW basis. Standard PDI was best in the CC400 treatment ($P \leq 0.05$) but there was no significant difference in modified PDI among the different corn particle treatments. Decreased standard and modified PDI were also observed ($P \leq 0.01$) due to the coarse expeller-extracted soybean meal (CESBM). Cumulative feed intake was not affected by CC treatments. However, improved BW at 43 d of age was exhibited by the CC800 treatment compared to

CC1200 treatment with CC400 and CC1600 treatments being intermediate ($P \leq 0.05$). Improved BW was evident in the CESBM treatment ($P \leq 0.05$) at 43 d of age. Improved AdjFCR was observed at 43 d with the CC800 and CC1200 treatments being better than the CC400 treatment with the CC1600 treatment being intermediate ($P \leq 0.05$). AdjFCR at 21 d was worse in broilers fed FESBM ($P \leq 0.05$) but the effect was absent thereafter. Relative gizzard weight was smallest in broilers fed CC400 treatment ($P \leq 0.01$). The current study clearly demonstrated that pellet quality was marginally affected by larger ingredient particles. However, this effect did not necessarily impact broiler live performance. Further, corn particle size was not the only factor that impacted performance and gizzard development since large corn particles over 1,190 µm were considered to have an indispensable role in gizzard development and feed efficiency. Large expeller SBM had no effect on gizzard development and overall feed efficiency, which was probably due to it being softer than CC and solvent extracted SBM and thus failed to stimulate reverse peristalsis. However, large expeller SBM seemed to promote decreased access of the GIT to the trypsin inhibitor contained therein.

Keywords: broiler live performance, pellet durability index, proventriculus, gizzard

4.2. INTRODUCTION

Larger particle size of grain in mash diets has been reported in several studies to improve the health of chickens as well as strongly influence gastrointestinal tract (GIT) development, motility, and function (Nir et al., 1995; Amerah et al., 2007). However, there has been controversy concerning the effects that fine particles versus larger particles had in pelleted diets. Hence, the study carried out in chapter III demonstrated numerically improved period

AdjFCR from 29-35 d of age in broilers fed CC800 treatment. This implied that the effect of CC may exist in pelleted diets. However, it was theorized that the effect was negated by large SBM particles and was linked to length of growing period as older birds that consumed more feed and had greater maintenance requirements appeared to benefit more from larger particles. Therefore, GMD of corn particle may not be the only factor that influenced GIT organ development. Large corn particle size distribution and large SBM had been brought to our attention and needed additional evaluation.

It has been suggested that source and processing of soybean meal (SBM) influenced growth performance and required chemical composition and quality controls (Serrano et al., 2012). Moreover, SBM particle size appeared to have been a confounding factor in the studies (Chapters II and III) that investigated a range of corn particle sizes. Expeller-extracted SBM (ESBM) was a co-product from processed whole SBM that contained higher trypsin inhibitors and fat, but less protein content and appeared to have a larger particle size than solvent-extracted SBM (SSBM). The purpose of this study was to evaluate the effects of different corn particle sizes replacing 50% of total dietary corn in combination with two expeller-extracted SBM particle sizes (fine versus coarse) in grower diets on pellet quality, broiler live performance, and proventriculus and gizzard weights. Attention was also given to potential particle size distribution with regards to impacts on live performance and proventriculus and gizzard weights.

4.3. MATERIALS AND METHODS

Hatching Eggs and Incubation. A total of 7,200 broiler hatching eggs were collected from 42-wk-old Ross 344 x 708 (Aviagen, Huntsville, AL) broiler breeders maintained at the research site. Preheating was conducted by moving the eggs into a room maintained at 26 to 28°C for 12 h with adequate air movement before bringing the eggs to a set point of 38.0°C through E3 of incubation in Jamesway setters. The dry bulb temperature was then changed and gradually decreased to 37.5°C from E3 to E12, 37.4°C from E13 to E15, and 37.2°C from E16 to E18 to maintain an internal egg temperature of 37.8°C or slightly below. The dry bulb temperature was independently confirmed and calibrated daily with a mercury thermometer. Relative humidity was maintained at 53% throughout incubation. The fresh air vent was initially closed until set point temperature was achieved and was at a minimum to E12 of incubation, and thereafter gradually increased to maximum at E15 of incubation.

Broiler Management. The experiment was conducted from December, 2014 to February, 2015, at the North Carolina State University Chicken Educational Unit, 4108 Lake Wheeler Road, Raleigh, NC. Animal handling conformed to the Guide for Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010). Broiler chicks were hatched, feather sexed, and maintained separately by breeder pen source before and after sexing. Thirty two male chicks were randomly selected with two chicks coming from each breeder pen such that breeder source and incubator position effects were equalized. Chicks were then permanently identified with neck tags, pen group weighed, and distributed onto used wood shaving litter after manual introduction to water and feed. Each pen had dimensions of 1.2 m wide by 3.6 m long with a stocking density of 7.4 birds per m^2. Each pen was equipped with one bell-type drinker and two manual tube feeder. The brooding temperature at reception was 35.0-36.1°C on the litter, which was determined with an infrared thermoscan gun, and was maintained through the first night before being decreased to 31.1-32.2°C the following morning. The litter temperature was maintained from 2 to 7 d at 31.1 to 32.2°C, 8 to 14 d at 29 to 30°C, 15 to 21 d at 26 to 27°C, and at 25 to 26°C thereafter with additional heaters. Water and broiler diets were provided for *ad libitum* consumption. Three supplemental feeder flats were used until 6 d of age, two flats to 7 d, and one flat to 8 d of age. There was 0.45 kg of broiler starter crumbles added per bird at 1 d of age. Small amounts of feed were moved out of the tube feeders onto the feeder flats once daily to 6 d of age. At 9 d of age, approximately 0.45 kg of broiler starter diet was added to bring the total to 0.9 kg per bird alive. The broiler feeding program was 0.9 kg/bird of starter and 5.4 kg/bird of grower diets. Feeders were shaken once per day throughout the experiment to maintain the flow of feed from tubes into pans. The lighting program schedule was 23 h of light from 1 to 7 d, 22 h of light from 8 to 14 d, 21 h of light from 15 to 21 d, and 14 h of light thereafter. House environment and birds were closely monitored and mortalities were weighed and recorded twice daily throughout the experiment.

Feed Formulation and Manufacturing. The experimental diets (Tables IV-1) were formulated mainly of corn and SBM. Diets were manufactured at the North Carolina State University Feed Mill Educational Unit. Corn was ground using a hammermill (Model 1522, Roskamp Champion, Waterloo, IA) equipped with two 2.4 mm (6/64 inch) screens to produce fine ground corn (FC). A two-pair roller mill (Model C128829, RMS, Harrisburg, SD) with different roller settings was used to produce the coarsely ground corn (CC) treatments. The two basal mash grower diets with either FESBM or CESBM were used to reduce ingredient variation. Dry ingredients were blended in a counterpoise mixer (Model TRDB126-0604, Hayes & Stolz, Fort Worth, TX) to create the basal diets. Each experimental grower diet was produced from the basal diet by replacement of FC with 50% of each CC treatment. The mash diet was then conditioned at 82 to 85°C and pelleted with a pellet mill (Model: 60-130, Bliss Industries LLC, Ponca City, OK) equipped with a 4.0 mm X 44 mm die. Pelleted diets were cooled with ambient air in a counter-flow cooler (Model: VK19X19KL, Geelen Counterflow USA Inc., Orlando, Florida). The starter diet was produced as crumbles and grower diets were produced as pellets.

Data Collection. The particle size of ground ingredients and mash grower diets were determined by dry sieving according to ASAE method S319.4 (ASABE, 2012; Stark and Chewning, 2012) with the addition of sieve agitators and 0.5 g of a dispersing agent per 100 g of sample (Silicon Dioxide, SSA-58, Gilson, Lewis Center, OH). Pelleted diets were collected at the pellet die for PDI analysis. Each treatment diet was collected 4 times at evenly spaced intervals upon discharge from the pellet mill. The pellet durability index (PDI) was determined according to the ASAE standard method S269.4 (ASABE, 2007). Initial BW of chicks was determined on a pen group basis and recorded on the day of placement. Thereafter, BW and feed intake were determined on a pen basis at 15, 22, 29, 36, and 43 d of age. All dead birds were removed, weighed, and recorded twice daily. Adjusted feed conversion ratio (AdjFCR) was calculated at 15, 22, 29, 36, and 43 d of age by including BW of all dead birds. At 45 d of age, 144 birds (2 birds per pen) were killed by cervical dislocation and individually weighed. The gizzard and proventriculus of each bird was excised, fat trimmed, and contents removed.

Both gizzard and proventriculus were weighed after rinsing and blotting dry, and expressed on both an absolute and relative to BW basis.

Data Analysis. Pelleted feed samples that were collected at the pellet die served as the experimental unit for PDI data. Pen served as the experimental unit for live performance data. Each bird served as an experimental unit for the proventriculus and gizzard weight data. The experimental design was a 4 x 2 factorial randomized complete block design so that each combination was replicated with 9 pens of 32 male birds each pen. All data were subjected to a two-way ANOVA to determine main effects and interactions by using the GLM procedure of SAS (SAS 9.4, SAS Institute, Cary, NC, USA, 2014). Differences among means was determined by least significant difference. Statements of statistical significance were based upon a probability level of $P \leq 0.05$ unless otherwise stated.

4.4. RESULTS AND DISCUSSION

The geometric mean diameter (GMD) and geometric standard deviation (GSD) of ground ingredients are shown in Table IV-2. The GMD of corn ground through the hammermill was determined to be 349 µm with a corresponding GSD of 2.85 for the CC400 treatment. The GMD of corn ground by the roller mill was determined to be 798, 1,276, and 1,602 µm with a corresponding GSD of 2.91, 2.93, and 2.89, respectively, for the CC800, CC1200, and CC1600 treatments, respectively. The GMD of the CC were in close agreement with the targeted particle size. Fine expeller-extracted SBM (ESBM) was ground by hammermill and determined to be 314 µm for the FESBM treatment, whereas coarse ESBM was determined to be 1,413 µm for the CESBM treatment. The particle size distributions of ingredients are shown graphically in Figure IV-1. As intended, the particle size distributions of the CC were not identical. Table IV-3 shows numerical details of GMD, GSD, and particle size distributions determined by the dry sieving according to ASAE method S319.4.

The GMD and GSD of grower diets in mash form are shown in Table IV-4. The GMD of mash grower diets in the presence of fine ESBM was determined to be 310, 403, 439, and 450 µm with a corresponding GSD of 2.77, 2.87, 3.03, and 3.24, respectively, for diet combinations CC400-FESBM, CC800-FESBM, CC1200-FESBM, and CC1600-FESBM, respectively. The GMD of grower diets in mash form in the presence of coarse ESBM was determined to be 512, 647, 724, and 862 µm with a corresponding GSD of 3.15, 2.97, 3.12, and 3.40, respectively, for diet combinations CC400-CESBM, CC800-CESBM, CC1200-CESBM, and CC1600-CESBM, respectively. The graphic comparison of the particle size distributions of grower diets in mash form is shown in Figure IV-2. As intended, the particle size distributions of the mash diets were not identical in the presence of fine versus coarse ESBM, especially with regards to the proportion of coarse particles (1,190 µm and over). The differences in particle size distribution were between 5.7 and 23.1% in mash diets containing fine ESBM and were between 21.9 and 47.4% in mash diets containing coarse ESBM with differences, notably in the proportion of coarse particles (1,190 µm and over) as detailed numerically in Table IV-5.

The effects of 50% CC of total dietary corn with different corn particle sizes in grower diets on pellet durability index (PDI) is shown in Table IV-6. There was evidence of an improved standard PDI of approximately 1% in the CC400 treatment diet ($P \leq 0.05$) as compared to diets containing greater corn particle sizes. However, modified PDI was not improved in the CC400 treatment. In addition, fine ESBM diets exhibited improved standard and modified PDI by 2.0% and 3.9%, respectively ($P \leq 0.01$) as compared to coarse ESMB diets. There was no significant interactions.

There was no main or interaction effects of different corn particle sizes or ESBM particle sizes on cumulative feed intake as shown in Table IV-7. However, period feed intake from 37-43 d was decreased in broilers fed CC1200 treatment relative to CC400 treatment with CC800 and CC1600 treatments intermediate ($P \leq 0.05$) as shown in Table IV-8.

The main and interaction effects of different corn particle sizes and ESBM particle sizes on BW are shown in Table IV-9. Broilers fed CC800 treatment exhibited greater BW at 43 d compared to CC1200 treatment with CC400 and CC1600 treatments intermediate ($P \leq 0.05$). In the same manner, chicks fed coarse ESBM exhibited greater BW compared to fine ESBM diet at 22 d ($P \leq 0.01$), 29 d, and 43 d of age ($P \leq 0.05$). There was an unexplained interaction effect at placement where the least BW was observed with CC1200 treatment in the presence of coarse ESBM particles ($P \leq 0.05$) but this was not apparent at later ages. These effects corresponded to period BW gain as presented in Table IV-10. Improved period BW gain during 37-43 d was observed in broilers fed CC800 treatment compared to CC400 and CC1200 treatments with CC1600 treatment intermediate ($P \leq 0.05$). With respect to ESBM particle size treatments, improved period BW gain during 16-22 d was observed ($P \leq 0.01$) in broilers fed coarse ESBM. There were no significant interactions.

The main and interaction effects of different corn particle sizes and ESBM particle sizes on AdjFCR are shown in Table IV-11. A beneficial effect of corn particle size on AdjFCR at 43 d was observed when broilers fed CC800 and CC1200 treatments performed better compared to the CC400 treatment with CC1600 treatment intermediate ($P \leq 0.05$). With reference to ESBM particle sizes, improved AdjFCR at 22 d was observed in chicks fed coarse ESBM ($P \leq 0.05$) but the effect was not evident thereafter. In the same manner, improved period AdjFCR during 37-43 d was observed in broilers fed CC800 and CC1600 treatments compared to the CC400 treatment with CC1200 treatment intermediate ($P \leq 0.05$). Finally, better period AdjFCR from 16 to 22 d was observed in chicks fed coarse ESBM ($P \leq 0.05$) as shown in Table IV-12. There was no significant interactions.

The main and interaction effects of different corn particle sizes and ESBM particle sizes on depletion are shown in Table IV-13. Cumulative depletion was not affected by corn and ESBM particle sizes.

The smallest absolute and relative weights of gizzard were evident in broilers fed the CC400 treatment compared to all across CC treatments ($P \leq 0.01$) as shown in Table IV-14. However, differences in proventriculus and gizzard weights were not observed for ESBM particle size treatments, which suggested that these size difference did not have an impact on GIT function. No significant interactions were observed.

The current study confirmed the traditional theory that improved pellet quality, as expressed by PDI was associated with smaller particle size grains (Wondra et al., 1995). However, decreased pellet quality did not necessarily have a negative effect on live performance. Broilers fed CC400 treatment, which had greater pellet quality compared to other corn particle size diets, exhibited poorer AdjFCR at 43 d while broilers fed coarse ESBM, which had poorer pellet quality compared to fine ESBM, exhibited greater BW at 43 d.

The study emphasized the complexity of optimizing feed particle size in broilers. Nevertheless, the study clearly demonstrated the positive effect of larger ground corn on gizzard size as evidenced by increased relative gizzard weight and improved feed efficiency in broilers consuming feed containing larger corn particles above 1,190 µm. This was similar to previous studies where broilers fed coarse feed particles exhibited an increased gizzard weight (Nir et al., 1995; Amerah et al., 2008). However, utilization of CC1600 treatment diminished feed efficiency, which was probably due to greater energy expenditure needed by the gizzard for grinding and hence less energy remained available for growth. In addition, differences in period feed intake, period BW gain, and period AdjFCR during 37-43 d of age implied that the effects of larger corn particle sizes was linked to the length of growing period as older birds consumed more feed but required more energy for growth and maintenance. So, optimum particle size and distribution should vary by age in order to balance slowed GIT passage and energy required by the gizzard for grinding, which was simply more energy being required for the exercise of the muscle rather than for growth and maintenance.

With respect to ESBM particle size, coarse ESBM appeared to benefit BW and AdjFCR, when chicks was exposed early to coarse ESBM. Pacheco et al. (2013) suggested that greater ESBM particle size ameliorated the negative effects of residual trypsin inhibitors because coarse ESBM enhanced reverse peristalsis in area of the gizzard and proventriculus and increased acid denaturation of trypsin inhibitors. Further, coarse ESBM released trypsin inhibitors more slowly and consistently and hence provided the broilers time for adaptation (Pacheco et al., 2014).

The results of the current study illustrated the positive effects on gizzard development and associated improved feed efficiency due to coarsely ground corn particles. Based on these data, corn particle sizes over 1,190 µm should comprise approximately 20% in a grower diet up to 43 d of age. On the contrary, coarse ESBM showed positive effects that were probably associated with deactivated trypsin inhibitors rather than enhanced reverse peristaltic properties because this ingredient was too soft as absence of a measurable effect as evidenced by no effect on relative gizzard weight.

4.5. REFERENCES

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Table IV-1. The composition of broiler starter diet and grower diets with fine expeller soybean meal (FESBM) or coarse expeller soybean meal (CESBM) and 50 percent of different coarsely ground corn (CC) particle size of total dietary corn

		Fine or coarse ESBM and Target particle size of CC (µm)							
	Starter	Grower							
		FESBM				CESBM			
Ingredients		400	800	1200	1600	400	800	1200	1600
	(%)								
Fine corn	55.53	31.08	31.08	31.08	31.08	31.08	31.08	31.08	31.08
Coarse corn	---	31.08	31.08	31.08	31.08	31.08	31.08	31.08	31.08
SBM (48% CP)	37.82	---	---	---	---	---	---	---	---
FESBM (40.8% CP)	---	32.89	32.89	32.89	32.89	---	---	---	---
CESBM (40.8% CP)	---	---	---	---	---	32.89	32.89	32.89	32.89
Poultry fat	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Dicalcium phosphate (18.5% P)	2.32	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Limestone	0.86	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Salt	0.48	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
DL-Methionine	0.25	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
L-Lysine-HCL (78%)	0.07	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
L-Threonine	0.13	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Choline chloride (60%)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Mineral premix [1]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin premix [2]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Selenium premix [3]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Coccidiostat [4]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calculated nutrients									
Protein	23.00	18.50	18.50	18.50	18.50	18.50	18.50	18.50	18.50
Calcium	1.00	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Available phosphorus	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Total lysine	1.31	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
Total methionine	0.59	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Total threonine	0.90	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Total methionine + cysteine	0.95	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
Sodium	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
ME, kcal/g	2.86	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Analyzed nutrients									
Protein	19.81	19.60	19.25	19.89	19.63	20.17	19.63	20.51	20.47
Fat	4.09	4.76	4.80	4.69	4.68	4.89	4.86	4.84	4.43
Fiber	3.00	3.00	3.40	3.00	3.50	3.40	3.50	3.30	3.20
Ash	5.76	5.36	5.07	4.77	5.21	5.24	5.17	5.22	5.14
Moisture	12.81	12.96	12.75	12.80	12.61	12.66	12.40	12.50	12.30

[1] Mineral premix supplied the following per kg of feed: Mn 108 mg, Zn 108 mg, Fe 72.6 mg, Cu 9 mg, I 2.2 mg, and Co 2.2 mg.

[2] Vitamin premix supplied the following per kg of feed: vitamin A 6608 IU, vitamin D_3 1982 IU; vitamin E 33 IU, vitamin B_6 3.9 mg, vitamin B_{12} 0.02 mg, biotin 0.13 mg, niacin 55 mg, thiamine 1.9 mg, riboflavin 6.6 mg, menadione (K_3) 1.9 mg, d-pantothenic acid 11 mg, and folic acid 1.1 mg.

[3] Selenium premix supplied Se at 0.3 mg per kg of feed.

[4] Coccidiostat supplied monensin sodium at 99 mg per kg of feed.

Table IV-2. Mean diameter particle size of ingredients

Ingredients and target particle size	Dgw[1]	Sgw[2]
	(µm)	
Fine corn (400 µm)	349	2.85
Coarse corn (800 µm)	798	2.91
Coarse corn (1200 µm)	1276	2.93
Coarse corn (1600 µm)	1602	2.89
Fine expeller soybean meal (FESBM)	314	2.37
Coarse expeller soybean meal (CESBM)	1413	3.00

[1] Geometric mean diameter was determined by dry sieving according to ASAE method S319.4 with the addition of sieve agitators and 0.5 g of a dispersing agent per 100 g of sample (ASABE, 2012; Stark and Chewning, 2012).
[2] Geometric standard deviation of mean particle size.

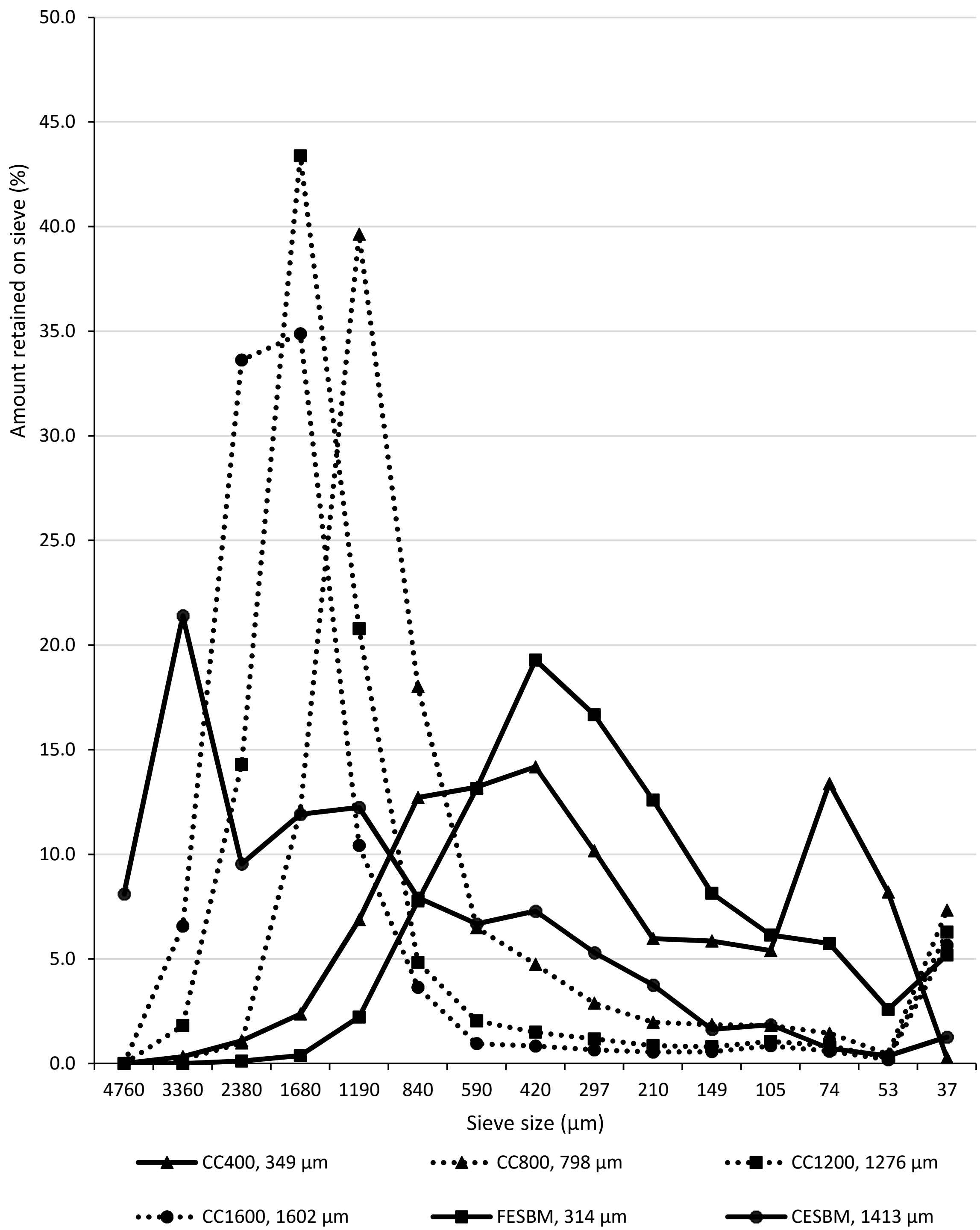

Figure IV-1. Particle size distribution of ingredients. CC = coarsely ground corn, FESBM = fine expeller soybean meal, CESBM = coarse expeller soybean meal. Actual particle size shown.

Table IV-3. Percentage particle size distribution and mean diameter particle size of coarsely ground corn (CC) and expeller soybean meal (ESBM)

		Fine or coarse ESBM and Target particle size of CC (µm)					
U.S. Sieve	Size	CC400	CC800	CC1200	CC1600	FESBM	CESBM
	(µm)	(%)					
4	4760	0.00	0.00	0.00	0.00	0.00	8.11
6	3360	0.33	0.21	1.81	6.58	0.00	21.40
8	2380	1.09	0.98	14.29	33.62	0.12	9.53
12	1680	2.37	12.10	43.38	34.87	0.38	11.91
16	1190	6.88	39.64	20.79	10.42	2.23	12.24
20	840	12.71	18.03	4.84	3.64	7.77	7.93
30	590	13.21	6.50	2.04	0.95	13.14	6.68
40	420	14.18	4.75	1.50	0.84	19.28	7.29
50	297	10.16	2.89	1.18	0.66	16.68	5.30
70	210	5.97	1.98	0.86	0.55	12.60	3.75
100	149	5.85	1.86	0.81	0.57	8.14	1.63
140	105	5.39	1.82	1.06	0.85	6.14	1.85
200	74	13.38	1.45	0.85	0.59	5.74	0.72
270	53	8.20	0.46	0.28	0.19	2.59	0.37
Pan	37	0.28	7.34	6.29	5.66	5.19	1.27
Dgw[1]		349	798	1276	1602	314	1413
Sgw[2]		2.85	2.91	2.93	2.89	2.37	3.00

[1] Geometric mean diameter was determined by dry sieving according to ASAE method S319.4 with the addition of sieve agitators and 0.5 g of a dispersing agent per 100 g of sample (ASABE, 2012; Stark and Chewning, 2012).
[2] Geometric standard deviation of mean particle size.

Table IV-4. Mean diameter particle size of mash grower diets

Target particle size of CC[1]	ESBM particle size[2]	Dgw[3]	Sgw[4]
(µm)		(µm)	
400	Fine	310	2.77
800	Fine	403	2.87
1200	Fine	439	3.03
1600	Fine	450	3.24
400	Coarse	512	3.15
800	Coarse	647	2.97
1200	Coarse	724	3.12
1600	Coarse	862	3.40

[1] Particle size of corn that comprised 50 percent of total dietary corn in grower diets.
[2] Particle size of expeller-extracted soybean meal (ESBM) in grower diets.
[3] Geometric mean diameter was determined by dry sieving according to ASAE method S319.4 with the addition of sieve agitators and 0.5 g of a dispersing agent per 100 g of sample (ASABE, 2012; Stark and Chewning, 2012).
[4] Geometric standard deviation of mean particle size.

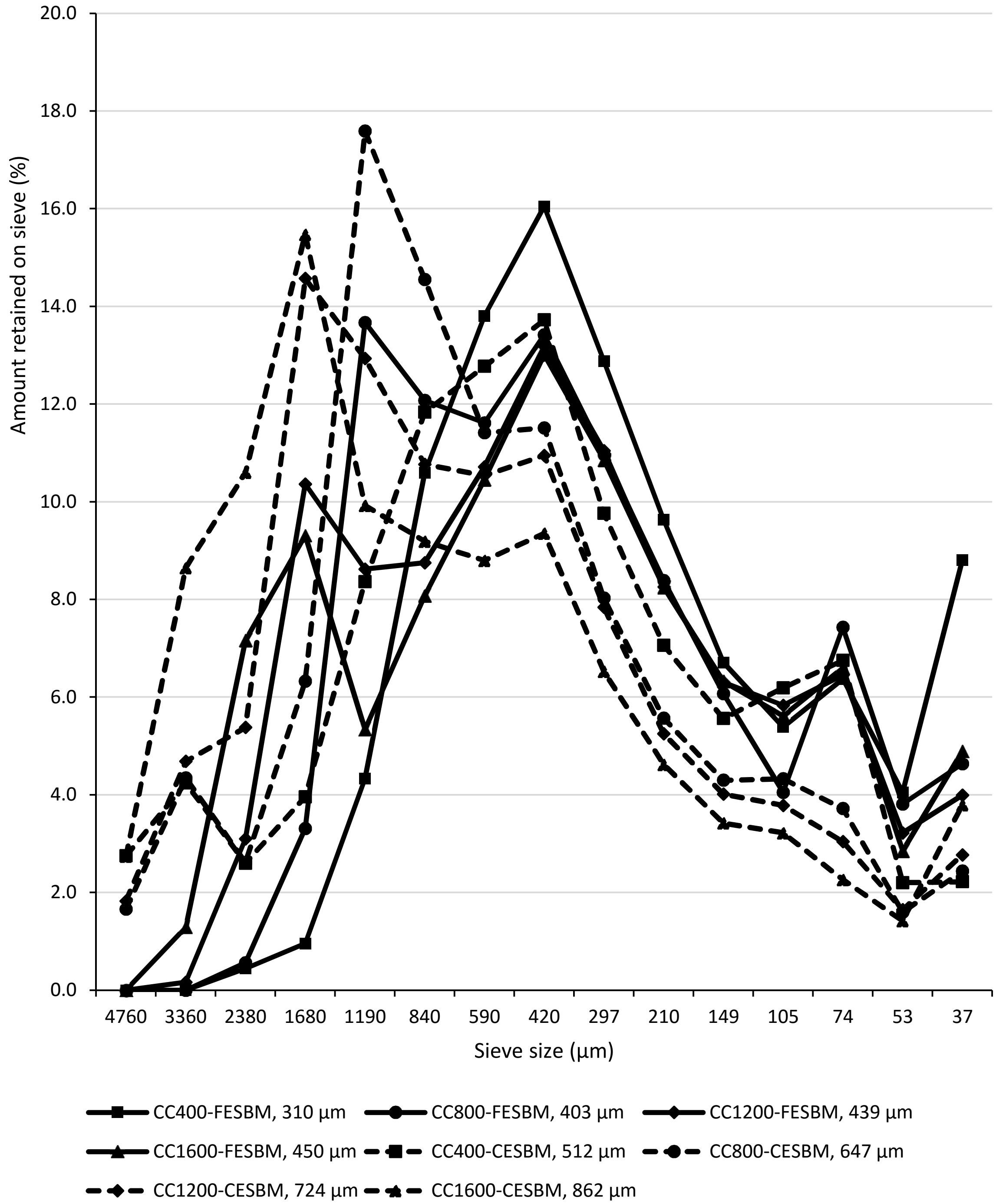

Figure IV-2. Particle size distribution of mash grower diets. CC = coarsely ground corn, FESBM = fine expeller soybean meal, CESBM = coarse expeller soybean meal. Actual particle size shown.

Table IV-5. Percentage particle size distribution and mean diameter particle size of mash grower diets

		Fine or coarse ESBM and Target particle size of CC (µm)							
		FESBM				CESBM			
U.S. Sieve	Size	400	800	1200	1600	400	800	1200	1600
	(µm)	(%)							
4	4760	0.00	0.00	0.00	0.00	2.75	1.66	1.83	2.74
6	3360	0.00	0.00	0.16	1.28	4.24	4.35	4.69	8.65
8	2380	0.44	0.56	3.10	7.16	2.60	2.62	5.38	10.60
12	1680	0.96	3.31	10.36	9.31	3.96	6.33	14.57	15.47
16	1190	4.33	13.67	8.62	5.34	8.36	17.59	12.94	9.93
20	840	10.59	12.08	8.75	8.07	11.83	14.55	10.77	9.19
30	590	13.80	11.61	10.71	10.45	12.77	11.41	10.54	8.80
40	420	16.05	13.42	13.18	13.01	13.72	11.51	10.95	9.35
50	297	12.88	10.96	11.04	10.85	9.76	8.03	7.84	6.52
70	210	9.63	8.39	8.26	8.24	7.06	5.57	5.25	4.62
100	149	6.71	6.07	6.30	6.32	5.56	4.30	4.01	3.42
140	105	5.39	4.05	5.83	5.62	6.19	4.33	3.78	3.22
200	74	6.37	7.43	6.45	6.60	6.75	3.72	3.04	2.27
270	53	4.05	3.81	3.22	2.85	2.20	1.60	1.65	1.42
Pan	37	8.81	4.63	3.99	4.89	2.22	2.44	2.77	3.80
Dgw[1]		310	403	439	450	512	647	724	862
Sgw[2]		2.77	2.87	3.03	3.24	3.15	2.97	3.12	3.40

[1] Geometric mean diameter was determined by dry sieving according to ASAE method S319.4 with the addition of sieve agitators and 0.5 g of a dispersing agent per 100 g of sample (ASABE, 2012; Stark and Chewning, 2012).
[2] Geometric standard deviation of mean particle size.

Table IV-6. Pellet durability index (PDI) of pelleted grower diets as affected by 50 percent of different coarsely ground corn (CC) particle size of total dietary corn, and fine and coarse expeller soybean meal (ESBM)

Target particle size of CC[1]	ESBM[2]	n[3]	PDI Standard[4]	PDI Modified[5]
(μm)			(%)	(%)
Main Effects				
400		8	95.0[A]	82.0
800		8	94.3[B]	79.9
1200		8	94.0[B]	80.2
1600		8	93.8[B]	81.2
SEM			0.257	0.728
P-value			0.014	0.195
	Fine	16	95.3[A]	82.8[A]
	Coarse	16	93.3[B]	78.9[B]
	SEM		0.182	0.515
	P-value		0.001	0.001
Interaction Effects				
400	Fine	4	95.7	83.6
800	Fine	4	95.8	83.3
1200	Fine	4	95.0	81.8
1600	Fine	4	94.7	82.5
400	Coarse	4	94.4	80.4
800	Coarse	4	92.8	76.6
1200	Coarse	4	92.9	78.7
1600	Coarse	4	93.0	80.0
SEM			0.364	1.030
P-value			0.142	0.182

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

[1] Particle size of corn that comprised 50 percent of total dietary corn in grower diets.

[2] Particle size of expeller-extracted soybean meal (ESBM) in grower diets.

[3] Number of samples collected at the pellet mill die.

[4] Pellet Durability Index (ASABE, 2007) was determined on samples collected at the pellet mill die.

[5] Pellet Durability Index (ASABE, 2007) was determined on samples collected at the pellet mill die with 3 nuts (diameter = 19 mm).

Table IV-7. Cumulative feed intake (FI) of broiler chickens as affected by main and interaction effects of 50 percent of different coarsely ground corn (CC) particle size of total dietary corn, and fine and coarse expeller soybean meal (ESBM)

Effects			Feed Intake and d of age				
Target CC particle size[1]	ESBM[2]	n[3]	15 d	22 d	29 d	36 d	43 d
(µm)			(g)				
Main Effects							
400		18	635	1438	2559	4032	5740
800		18	643	1446	2566	4027	5715
1200		18	638	1432	2532	3977	5634
1600		18	637	1437	2545	4003	5691
SEM			4.7	8.2	15.2	21.5	30.0
P-value			0.701	0.665	0.411	0.250	0.091
	Fine	36	636	1433	2539	4001	5681
	Coarse	36	641	1444	2561	4019	5708
	SEM		3.3	5.7	10.7	15.2	21.2
	P-value		0.276	0.185	0.155	0.417	0.373
Interaction Effects							
400	Fine	9	635	1430	2542	4019	5727
800	Fine	9	640	1444	2559	4028	5717
1200	Fine	9	637	1431	2535	3985	5629
1600	Fine	9	630	1427	2522	3973	5654
400	Coarse	9	636	1447	2576	4045	5752
800	Coarse	9	646	1448	2572	4027	5714
1200	Coarse	9	638	1433	2529	3969	5639
1600	Coarse	9	644	1448	2569	4034	5728
SEM			6.7	11.5	21.5	30.4	42.5
P-value			0.762	0.796	0.629	0.604	0.815

[1] Particle size of corn that comprised 50 percent of total dietary corn in grower diets.
[2] Particle size of expeller-extracted soybean meal (ESBM) in grower diets.
[3] Number of replicate pens of 32 birds each.

Table IV-8. Period feed intake (FI) of broiler chickens as affected by main and interaction effects of 50 percent of different coarsely ground corn (CC) particle size of total dietary corn, and fine and coarse expeller soybean meal (ESBM)

Effects			Period feed intake and d of age				
Target CC particle size[1]	ESBM[2]	n[3]	1-15 d	16-22 d	23-29 d	30-36 d	37-43 d
(µm)			(g)				
Main Effects							
400		18	635	803	1120	1473	1707[a]
800		18	643	803	1119	1461	1688[ab]
1200		18	638	793	1100	1444	1657[b]
1600		18	637	799	1108	1458	1687[ab]
SEM			4.7	4.2	8.0	7.6	10.8
P-value			0.701	0.358	0.232	0.074	0.019
	Fine	36	636	797	1106	1461	1680
	Coarse	36	641	802	1117	1457	1689
	SEM		3.3	3.0	5.6	5.3	7.6
	P-value		0.276	0.180	0.179	0.563	0.386
Interaction Effects							
400	Fine	9	635	794	1112	1477	1707
800	Fine	9	640	803	1115	1468	1688
1200	Fine	9	637	793	1103	1450	1644
1600	Fine	9	630	796	1095	1450	1681
400	Coarse	9	636	811	1128	1469	1706
800	Coarse	9	646	802	1124	1454	1687
1200	Coarse	9	638	793	1096	1439	1670
1600	Coarse	9	644	803	1121	1465	1694
SEM			6.7	6.0	11.3	10.7	15.3
P-value			0.762	0.459	0.519	0.548	0.778

[a, b, c] Means within each column that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Particle size of corn that comprised 50 percent of total dietary corn in grower diets.
[2] Particle size of expeller-extracted soybean meal (ESBM) in grower diets.
[3] Number of replicate pens of 32 birds each.

Table IV-9. Cumulative BW of broiler chickens as affected by main and interaction effects of 50 percent of different coarsely ground corn (CC) particle size of total dietary corn, and fine and coarse expeller soybean meal (ESBM)

Effects			BW and d of age					
Target CC particle size[1]	ESBM[2]	n[3]	1 d	15 d	22 d	29 d	36 d	43 d
(µm)			(g)					
Main Effects								
400		18	44.0	526	1071	1808	2701	3621^{ab}
800		18	44.1	535	1080	1826	2710	3658^{a}
1200		18	43.9	527	1067	1798	2681	3590^{b}
1600		18	43.9	527	1072	1804	2693	3619^{ab}
SEM			0.13	4.0	5.4	10.1	11.7	15.7
P-value			0.791	0.384	0.429	0.242	0.359	0.029
	Fine	36	44.0	526	1063^{B}	1797^{b}	2687	3606^{b}
	Coarse	36	44.0	531	1081^{A}	1821^{a}	2705	3639^{a}
	SEM		0.09	2.8	3.8	7.1	8.3	11.1
	P-value		0.966	0.204	0.001	0.023	0.132	0.040
Interaction Effects								
400	Fine	9	43.9^{ab}	522	1057	1788	2686	3602
800	Fine	9	43.9^{ab}	532	1074	1820	2718	3653
1200	Fine	9	44.3^{a}	527	1062	1797	2685	3581
1600	Fine	9	43.9^{ab}	523	1060	1784	2660	3587
400	Coarse	9	44.1^{ab}	530	1084	1829	2717	3641
800	Coarse	9	44.3^{a}	538	1085	1832	2701	3664
1200	Coarse	9	43.6^{b}	526	1072	1798	2677	3598
1600	Coarse	9	44.0^{ab}	531	1084	1825	2726	3652
SEM			0.18	5.7	7.6	14.3	16.6	22.2
P-value			0.030	0.868	0.592	0.410	0.060	0.625

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

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

[1] Particle size of corn that comprised 50 percent of total dietary corn in grower diets.

[2] Particle size of expeller-extracted soybean meal (ESBM) in grower diets.

[3] Number of replicate pens of 32 birds each.

Table IV-10. Period BW gain of broiler chickens as affected by main and interaction effects of 50 percent of different coarsely ground corn (CC) particle size of total dietary corn, and fine and coarse expeller soybean meal (ESBM)

Effects			Period BW gain and d of age				
Target CC particle size[1]	ESBM[2]	n[3]	1-15 d	16-22 d	23-29 d	30-36 d	37-43 d
(µm)			(g)				
Main Effects							
400		18	482	544	737	892	920^{b}
800		18	491	545	746	883	948^{a}
1200		18	483	540	730	882	909^{b}
1600		18	483	545	732	889	926^{ab}
SEM			4.0	2.7	6.4	6.9	9.1
P-value			0.399	0.544	0.315	0.707	0.026
	Fine	36	482	537^{B}	733	889	918
	Coarse	36	487	550^{A}	739	884	933
	SEM		2.8	1.9	4.5	4.9	6.5
	P-value		0.205	0.001	0.380	0.424	0.108
Interaction Effects							
400	Fine	9	478	534	731	897	915
800	Fine	9	488	542	745	897	935
1200	Fine	9	483	535	734	887	896
1600	Fine	9	479	537	723	876	926
400	Coarse	9	485	554	744	888	924
800	Coarse	9	493	547	746	869	962
1200	Coarse	9	483	545	726	878	921
1600	Coarse	9	487	553	740	901	925
SEM			5.7	3.8	9.1	9.8	13.0
P-value			0.889	0.289	0.497	0.065	0.639

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

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

[1] Particle size of corn that comprised 50 percent of total dietary corn in grower diets.

[2] Particle size of expeller-extracted soybean meal (ESBM) in grower diets.

[3] Number of replicate pens of 32 birds each.

Table IV-11. Cumulative adjusted feed conversion ratio (AdjFCR) of broiler chickens as affected by main and interaction effects of 50 percent of different coarsely ground corn (CC) particle size of total dietary corn, and fine and coarse expeller soybean meal (ESBM)

Effects			AdjFCR and d of age				
Target CC particle size[1]	ESBM[2]	n[3]	15 d	22 d	29 d	36 d	43 d
(µm)			(g feed : g BW gain)				
Main Effects							
400		18	1.318	1.402	1.451	1.522	1.615[a]
800		18	1.311	1.398	1.442	1.516	1.594[b]
1200		18	1.322	1.403	1.446	1.514	1.601[b]
1600		18	1.322	1.404	1.449	1.521	1.602[ab]
SEM			0.005	0.004	0.003	0.005	0.004
P-value			0.475	0.818	0.280	0.701	0.021
	Fine	36	1.320	1.407[a]	1.450	1.518	1.604
	Coarse	36	1.317	1.396[b]	1.444	1.518	1.601
	SEM		0.003	0.003	0.002	0.004	0.003
	P-value		0.485	0.035	0.114	0.894	0.517
Interaction Effects							
400	Fine	9	1.327	1.411	1.457	1.528	1.620
800	Fine	9	1.314	1.404	1.444	1.510	1.593
1200	Fine	9	1.322	1.406	1.448	1.511	1.603
1600	Fine	9	1.319	1.406	1.451	1.524	1.602
400	Coarse	9	1.309	1.394	1.445	1.517	1.610
800	Coarse	9	1.309	1.391	1.439	1.521	1.594
1200	Coarse	9	1.323	1.400	1.445	1.516	1.598
1600	Coarse	9	1.325	1.402	1.448	1.517	1.602
SEM			0.007	0.006	0.005	0.008	0.006
P-value			0.437	0.738	0.772	0.504	0.844

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

[1] Particle size of corn that comprised 50 percent of total dietary corn in grower diets.

[2] Particle size of expeller-extracted soybean meal (ESBM) in grower diets.

[3] Number of replicate pens of 32 birds each.

Table IV-12. Period adjusted feed conversion ratio (AdjFCR) of broiler chickens as affected by main and interaction effects of 50 percent of different coarsely ground corn (CC) particle size of total dietary corn, and fine and coarse expeller soybean meal (ESBM)

Effects			Period AdjFCR and d of age				
Target CC particle size[1]	ESBM[2]	n[3]	1-15 d	16-22 d	23-29 d	30-36 d	37-43 d
(µm)			(g feed : g BW gain)				
Main Effects							
400		18	1.318	1.477	1.520	1.666	1.895[a]
800		18	1.311	1.477	1.503	1.671	1.828[b]
1200		18	1.322	1.476	1.508	1.652	1.865[ab]
1600		18	1.322	1.479	1.515	1.670	1.844[b]
SEM			0.005	0.007	0.005	0.017	0.017
P-value			0.475	0.995	0.170	0.862	0.049
	Fine	36	1.320	1.486[a]	1.511	1.658	1.863
	Coarse	36	1.317	1.469[b]	1.512	1.671	1.853
	SEM		0.003	0.005	0.004	0.012	0.012
	P-value		0.485	0.033	0.950	0.468	0.575
Interaction Effects							
400	Fine	9	1.327	1.487	1.524	1.670	1.892
800	Fine	9	1.314	1.488	1.500	1.643	1.841
1200	Fine	9	1.322	1.483	1.506	1.639	1.888
1600	Fine	9	1.319	1.486	1.515	1.681	1.831
400	Coarse	9	1.309	1.468	1.517	1.662	1.898
800	Coarse	9	1.309	1.466	1.506	1.700	1.815
1200	Coarse	9	1.323	1.470	1.510	1.664	1.843
1600	Coarse	9	1.325	1.472	1.514	1.658	1.858
SEM			0.007	0.011	0.008	0.025	0.024
P-value			0.437	0.976	0.870	0.401	0.478

[a, b] Means within each column that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Particle size of corn that comprised 50 percent of total dietary corn in grower diets.
[2] Particle size of expeller-extracted soybean meal (ESBM) in grower diets.
[3] Number of replicate pens of 32 birds each.

Table IV-13. Cumulative depletion of broiler chickens as affected by main and interaction effects of 50 percent of different coarsely ground corn (CC) particle size of total dietary corn, and fine and coarse expeller soybean meal (ESBM)

Effects			Depletion and d of age				
Target CC particle size[1]	ESBM[2]	n[3]	15 d	22 d	29 d	36 d	43 d
(µm)			(%)				
Main Effects							
400		18	0.34	0.52	0.52	1.39	2.78
800		18	0.17	0.17	0.52	0.86	2.77
1200		18	0.17	0.52	0.69	1.91	3.99
1600		18	0.52	1.21	1.39	2.43	3.47
SEM			0.222	0.296	0.369	0.514	0.854
P-value			0.643	0.100	0.297	0.175	0.698
	Fine	36	0.43	0.69	1.04	1.91	2.95
	Coarse	36	0.17	0.52	0.52	1.39	3.56
	SEM		0.157	0.209	0.261	0.363	0.604
	P-value		0.245	0.559	0.163	0.315	0.480
Interaction Effects							
400	Fine	9	0.69	1.04	1.04	1.39	2.08
800	Fine	9	0.34	0.34	1.04	1.39	2.43
1200	Fine	9	0.34	0.34	0.69	1.73	3.47
1600	Fine	9	0.34	1.04	1.39	3.12	3.82
400	Coarse	9	0.00	0.00	0.00	1.39	3.47
800	Coarse	9	0.00	0.00	0.00	0.34	3.12
1200	Coarse	9	0.00	0.69	0.69	2.08	4.51
1600	Coarse	9	0.69	1.39	1.39	1.73	3.12
SEM			0.314	0.418	0.522	0.727	1.208
P-value			0.413	0.295	0.577	0.589	0.835

[1] Particle size of corn that comprised 50 percent of total dietary corn in grower diets.
[2] Particle size of expeller-extracted soybean meal (ESBM) in grower diets.
[3] Number of replicate pens of 32 birds each.

Table IV-14. Absolute and relative weights of the proventriculus and gizzard of broiler chickens at 45 d of age as affected by main and interaction effects of 50 percent of different coarsely ground corn (CC) particle size of total dietary corn, and fine and coarse expeller soybean meal (ESBM)

Effects			Proventriculus		Gizzard	
Target CC particle size[1]	ESBM[2]	n[3]	Absolute	Relative	Absolute	Relative
(µm)			(g)	(g/100 g BW)	(g)	(g/100 g BW)
Main Effects						
400		36	10.25	0.27	27.97^{B}	0.74^{B}
800		36	10.43	0.28	33.66^{A}	0.89^{A}
1200		36	9.89	0.26	34.38^{A}	0.91^{A}
1600		36	9.73	0.25	33.60^{A}	0.88^{A}
SEM			0.324	0.008	0.865	0.022
P-value			0.401	0.289	0.001	0.001
	Fine	72	10.00	0.26	32.68	0.86
	Coarse	72	10.15	0.27	32.12	0.84
	SEM		0.229	0.005	0.611	0.015
	P-value		0.635	0.786	0.517	0.400
Interaction Effects						
400	Fine	18	10.62	0.28	27.01	0.71
800	Fine	18	10.18	0.27	35.06	0.93
1200	Fine	18	10.06	0.27	34.16	0.91
1600	Fine	18	9.13	0.24	34.50	0.90
400	Coarse	18	9.89	0.26	28.93	0.77
800	Coarse	18	10.68	0.28	32.26	0.85
1200	Coarse	18	9.71	0.25	34.60	0.90
1600	Coarse	18	10.33	0.27	32.69	0.86
SEM			0.458	0.011	1.223	0.031
P-value			0.159	0.102	0.211	0.217

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

[1] Particle size of corn that comprised 50 percent of total dietary corn in grower diets.

[2] Particle size of expeller-extracted soybean meal (ESBM) in grower diets.

[3] Number of chickens with 2 from each pen.

CHAPTER V

CONCLUSION AND DISCUSSION

5.1. OVERALL CONCLUSION AND DISCUSSION

High feed costs and environment sustainability have always been major issues for poultry production. The environmental impacts of concentrated areas of intensive poultry production have been increasingly targeted by regulations. Intensive poultry production has resulted in the release of several pollutants to the environment that have been believed to contribute significantly to regional pollution. Therefore, feed efficiency has become more critically important as a means to remain cost competitive and promote environmental sustainability of commercial poultry production. Fine particles have been historically thought to be beneficial in terms of better enzymatic digestion and improved pellet durability (Behnke, 2001), which has been generally recognized to positively influence feed characteristics (Briggs et al., 1999) and improve feed efficiency (McKinney and Teeter, 2004). However, it has been suggested that a certain percentage of large particle size ingredients enhanced the development of digestive tract, especially the gizzard and associated GIT neural plexus and smooth muscles so as to decrease the digesta passage rate, which has been reported to improve feed efficiency (Amerah et al., 2008). Even though available data clearly suggested that grain particle size was more critical in mash feeds than in pelleted or crumbled feeds, there has remained interest in studying the effects of particle size in crumble/pelleted diets on the basis that the pellets dissolve in the crop, proventriculus, and gizzard after consumption and hence that the effect of feed particle size may be maintained even after pelleting (Nir et al., 1995).

The current series of research studies were designed to test the effects of liquid fat application, expeller-extracted SBM, and corn particle size on pellet quality and broiler live performance. In addition, proventriculus and gizzard weights were determined to assess the influence of these factors on GIT development and function. It was believed that understanding the factors that impacted pellet quality and broiler live performance throughout the entire broiler integration would allow us to develop tools for making better decisions. The present chapter summarized and discussed the integrated concepts that emerged from this research.

The data detailed in Chapters II and IV confirmed the traditional theory that improved pellet quality, as expressed by PDI, was associated with smaller feed ingredient particle size (Wandra et al., 1995) due to greater surface area to accept moisture during conditioning and make contact during pelleting (Turner, 1995). Our data demonstrated that greater corn particle size negatively influenced PDI by approximately 5%. These results were similar to those for expeller-extracted SBM. However, data from Chapter III indicated that with appropriate formulation and feed manufacturing technique good pellet quality could be achieved even with large corn particles by addition of pellet binder and feed ingredients such as wheat that have been recognized as having positive binding characteristics (Winowiski, 1988). The study from Chapter II also demonstrated that adding more mixer fat to pelleted diets decreased pellet quality probably because fat functioned as a lubricant in the pellet die and decreased die friction that was required to form each pellet. Nevertheless, the manner in which fat was applied was important to ameliorate adverse effects on pellet quality. Post-pellet liquid fat application was an important method used in high energy diet that comprised high level of liquid fat to avoid negative impacts on pellet quality.

It has been believed that good pellet quality contributed positive effects on broiler live performance from increased feed intake with less energy being used for prehension and most investigations have emphasized the negative effect of large feed ingredient particles on pellet quality. However, the present work showed that large particles influenced pellet quality less than 5%, which may not be meaningful to a commercial integrator as long as reduced feed intake per bird and a cost competitive operation was achieved. This was confirmed by the present series of studies.

The results on broiler live performance from Chapter II implied that the positive effect of corn particle size was transient in pelleted diets and that broilers may require a specific corn particle size for various ages. The study in Chapter III demonstrated that the positive effect of corn particle size was evident as a numerically improved period AdjFCR in older broilers, which confirmed that the effect of CC was linked to age as older birds consumed more feed and benefited more from larger particle that slowed gut passage rate relative to the extra energy required for the increased muscle activity. However, the combined results from Chapters II and III clearly indicated that corn particle size was not the only factor that impacted GIT development and broiler live performance. Large corn versus SBM particle size has been brought to our attention. Further data from Chapter IV indicated that large corn particles over 1,190 µm needed to be approximately 20% of the feed in order to contribute significantly in terms of increased relative gizzard size and improved feed efficiency. In agreement with Nir et al. (1995), larger particle sizes influenced GIT development and improved performance in broilers through intestinal development and function, especially the gizzard. The results from the current study supported this concept. Therefore, in order to enhance gizzard development, corn particle sizes greater than 1,190 µm were most important to adequately influence GIT development, motility, and function. As more large corn particles were added to the diet, a larger relative gizzard size developed as demonstrated in Chapter IV. However, the fact that more than 20% of total feed being corn particles over 1,190 µm diminished feed efficiency implied that it was not necessary to include very large corn particles in a diet, which was probably because greater energy expenditure would be needed by the gizzard for grinding. Therefore, a balance between the advantages and disadvantages of an increased gizzard size and activity would be required in which optimum corn particles over 1,190 µm should vary by age in order to balance slowed GIT passage and energy required by the gizzard for grinding. This would simply provide more energy for growth and maintenance rather than for gizzard and intestinal muscular activity. The current series of studies demonstrated both the positive effects and the complexity of optimizing corn particle sizes in pelleted diets on live performance and GIT organ development. It was determined that 17-22% of total corn in a broiler diet from 16-43 d of age needed to be greater than 1,190 µm in order to balance the benefits of slowed digesta passage with increased muscular activity of the gizzard and GIT.

In addition, results with expeller SBM particles from Chapter IV supported the concept that larger particles likely benefited live performance as demonstrated by improved BW even though overall feed efficiency and relative gizzard size were not affected by large expeller SBM particle size in the study due to its softness compared to solvent extracted SBM. These effects were associated with enhanced reverse peristalsis that may have increased denaturation of trypsin inhibitors as well as limited access of intestinal enzymes to the inhibitors (Pacheco et al., 2013). Results with coarse ESBM in this study showed positive effects that were probably associated with sequestered trypsin inhibitors rather than enhanced reverse peristaltic properties because this ingredient was physically softer than solvent extracted SBM as evidenced by an absence of a measurable effect on relative gizzard weight in Chapter IV. Therefore, results might have been different if solvent extracted SBM was used instead of expeller SBM. Thus, the texture, size, and hardness of multiple feed ingredients should be considered when designing a feed particle size strategy.

5.2. REFERENCES

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