EFFECTs OF CORN STARCH ON GROWTH PERFORMANCE OF BROILER CHICKS DURING THE EARLY GROWTH PERIOD

by

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Abstract

Three experiments were conducted to evaluate the effects of gelatinized starch created during the pelleting process. Effects of gelatinization were first broadly tested to find if either increased or decreased gelatinization levels would increase broiler weight gain and feed efficiency during the starter period, 0 to 21 days of age. Results of the first experiment indicated a decrease ($P<0.05$) in broiler performance with increased levels of gelatinization, and a significant effect when the inclusion of gelatinized starch in the diet increased from 0 to 35%. A second experiment was conducted using a smaller range, 0 to 21% versus 0 to 35% inclusion of gelatinized starch in the diet and a smaller increment of increase, 3 versus 5%. Results of this experiment confirmed the results of the first experiment, and regression analysis was performed on the data. A linear decrease in body weight gain and quadratic increase in feed:gain ($P<0.05$) was observed as gelatinized starch was increased from 0 to 21% of the diet. A survey of the literature was conducted showing that most of the simulated levels of gelatinization were larger than those achieved with typical pelleted broiler diets. A third experiment was designed to investigate the levels of gelatinization observed in a pelleted diet and combined with three corn particle sizes, small (466 µm), medium (878 µm), and large (1240 µm), to find if any interactions existed. Chicks fed with the highest gelatinization level of 20%, (7.86% inclusion of pregelatinized starch) had lower body weight gains ($P<0.05$), and higher feed:gain ($P<0.05$) compared to chicks fed with 0% gelatinization. Small particle size had the lowest live body weight gain and lowest pen feed intake ($P<0.05$). There were no interactions found between

gelatinization level and particle size (*P*>0.10). The results demonstrated a negative effect on chick body weight gain and feed efficiency by gelatinization of starch.

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Dedication

I dedicate this thesis to my parents, Karla and Tim Rude, and to my brother Jon Rude. While you may have not understood why I decided to stay in school this long, you supported me and reassured me when things were not going as I had planned or hoped.

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CHAPTER 1 - Literature Review

Introduction

Modern day, meat-type chickens (broilers) are fed pelleted feed. Pelleting introduces heat and moisture in the form of steam and friction, thereby changing chemical structure. In a review conducted by Calet (1965) pelleting was found to improve bird gain and performance, and research conducted since has demonstrated positive effects of pelleting on performance. Research has yielded numerous theories concerning the mechanism by which pelleting improves growth performance. Main theories are 1) preventing sorting of the feed by agglomerating diet constituents into a homogeneous pellet, 2) reducing time spent consuming feed, and 3) inducing positive chemical changes. All of these theories have merit, but no comprehensive research efforts have been undertaken to determine the mechanism of action. An improvement in pellets at the feed pan (i.e. pellet quality) has been shown to increase growth performance of broilers (McKinney and Teeter, 2004). This research demonstrates the importance of the pellets remaining intact at the feed pan, not only processed through a pellet mill. However, research conducted using an expander (which gelatinizes starch using pressure, heat, and steam) demonstrated increased pellet durability index (**PDI**) without the desired increase in broiler growth performance (Cramer et al., 2003). This contradictory research complicates the question of why pelleting increases growth performance for broilers.

Broiler feed, often has 40 to 50% corn and corn is 70 to 75% starch. Thus a typical broiler starter diet has 28 to 38% starch. Given the importance placed on efficient use of feed in the broiler industry, and starch being more than 1/3 of the diet, efficient breakdown of starch is important to the poultry industry.

Unlike its mammalian counterparts in the meat industry, broiler chicks never receive milk. The first meal a chick consumes is primarily corn and soybean meal. Hatchling chicks are well equipped to handle a corn-soy diet, having the enzymes necessary for digestion in already formed in the pancreas (Marchaim and Kulka, 1967). However the digestive tract is not fully mature at hatching and feed processing is proposed as a means of enhancing nutrient utilization.

Effects of Feed Processing on Diet, Growth, and Nutrient Utilization

A pellet mill has two main components, the conditioner and the roller/die. Roller forms pellets by forcing feed through the die. Dies can have different hole size and number, and the pellets can be cut to different lengths. The conditioner adds heat and moisture, in the form of steam, to the diet to aid in pellet formation. Forcing feed through the die generates heat via friction. The pellets are then cooled and either put in bags or a bin. Heat imparted into the diet by the pellet mill has been proposed as a possible reason for the improvement in growth performance.

Heat Processing

Corn is processed by heating to 104 ^{o}C for 60 min. and then flaked and ground impaired broiler weight gain and feed:gain from d 0 to 21 (Gonzalez-Alvarado et al., 2007). This feed was not in a pellet form so texture differences between diets may have affected bird performance. Corn processed by exposing to steam for four hours, or autoclaving resulted in no improvement in growth performance (Allred et al., 1957). Another way to increase the corn’s exposure to high heat and moisture is to process with an extruder. An extruder uses mechanical energy, moisture, and heat to cook ingredients and pushes them through a die at high pressure. In a paper published by Amornthewaphat et al. (2005), corn was processed through an extruder incorporated at a level of 25% of a diet fed as either mash or pellets. No difference was observed among extrusion processed corn and unprocessed corn. Pelleted unprocessed corn diet had a gelatinization level of 8 % whereas pelleted extrusion processed corn diet had a gelatinization level of 39%. Previous paper's results are supported by Moritz et al. (2005), where corn was pelleted or extruded resulting in starch gelatinization levels of 29 and 92% respectively. An expander is a simpler form of an extruder, imparting less moisture, mechanical force, and pressure. In the simplest description an expander pushes the product through a small die and past a cone, and pressure is controlled by the distance between the cone and the die. This imparts a large amount of energy into the product, resulting in gelatinizing of the starch, and increased PDI. However, increases in PDI from 30 to 90% and starch gelatinization from 10 to 35%, did not improve the gain or feed efficiency of broilers d 0 to 21 (Cramer et al., 2003). These results are supported by earlier research where gelatinizing purified starch had negative effects at a level as low as 12.5% (Burnett, 1963).

With evidence of processing corn or diets through a process involving high heat and moisture showing no effect or negative results, different approaches were taken to improve pellet quality and broiler performance. By adding moisture to the mash prior to pelleting, the PDI increased from 51 to 77%, and starch gelatinization increased from 7 to 13%. This increase in PDI did not translate into improved live weight gain, and resulted in poorer feed efficiency during the starter period (0-3 weeks) (Moritz et al., 2001). In a follow up study using the grower growth period (3-6 weeks) the addition of moisture actually decreased starch gelatinization, which was attributed to reduced die friction, and increased the PDI. The difference in PDI or starch gelatinization did not result in any change in either live weight gain or feed efficiency (Moritz et al., 2003). While the starch gelatinization was significantly different varying from 6 to 24%, PDI was similar between the diets and could explain descrepency.

Digestive Effects of Pelleting

Hardness is another measurement of pellet quality. In an experiment conducted by Nir et al. (1994c) pellets were produced with different levels of hardness, soft or hard. Pelleted diets outperformed the mash diet, however the increase in growth performance was reduced when chicks were fed either blended (1:1 soft to hard pellets) pellet diet or hard pellet only diet. Pelleted diets decreased the length of the jejunum and ileum by about 15% when compared to mash diets. Intestinal weight/length ratio's increased with pelleted diets however the hard pellet only diet's weight/length was lower than the blended diet's weight/length ratio. The authors also found a reduction in the activity of amylase in the intestines of pellet fed birds. A decrease seen in gastrointestinal tract length by pellets is supported by Choi et al. (1986), where gizzard and total gastrointestinal tract weights were reduced by pelleting. Reduced gizzard size is contradicted by the research conducted by Dahlke et al. (2003), where higher intestinal weight of pellet fed birds, and intestinal characteristics were observed. Birds fed pelleted diets had greater villus number, lower villus height, and greater crypt depth, indicative of a pathogenically challenged intestine. Effects on surface area of the small intestine were not discussed.

Digestibility of Pellets

With pelleting clearly having an effect on the digestive system of a chicken, then what are there effects on the metabolizable energy or digestibility? Early work conducted by Bolton (1960) showed a similarity between the digestibility of mash and pelleted diets fed to chicks from 0 to 9 weeks of age. This research is supported by Savory (1974), where laying-type chickens were fed mash or pelleted diets from 0-40 days. Digestibility was similar for hybrid layers, even with improved gain however pure Brown Leghorns appeared to have higher digestibilities when fed a pelleted diet. Hussar and Robblee (1962) explored the metabolizable energy of pelleted diets by feeding White Plymouth Rock chicks from 0-42 days, and found even with pellet fed birds had higher weight gains and better feed conversion, all diets had similar apparent metabolizable energy. The research included a chart with the calculated pellet temperature as affected by length of time the pellet mill was operated. This chart showed an increase from 30 to 72 ^{o}C from 0 to 26 minutes, but showed stabilization in temperature after 48 minutes at 69 ^{o}C. Findings of previous research were confirmed in research conducted by Reddy et al. (1962), where White Leghorns were fed for four weeks, and no difference was found between metabolizable energy of pelleted, ground pellets, or mash diets. Research using meat type chickens indicated a higher metabolizable energy in pelleted versus mash diets (Bayley et al. 1968). A higher metabolizable energy was also found for pelleted diets with reduced levels of protein, metabolizable energy and phosphorus, but this was attributed to increased efficiency due to low nutrient levels. Previous research measured metabolizable energy of pellets using apparent metabolizable energy. True metabolizable energy involves the feeding of cecectomized rooster, and analyzing the fecal output. Research conducted using this method concluded that there was a small difference between pelleted and mash diets, and after running a statistical t-test the differences are not found to be significant (Sibbald, 1977).

Starch Formation, Structure, and Digestion

Starch is the principle way that higher plants reserve energy obtained from photosynthesis (Banks and Muir, 1980). Starch is a polymer of glucose, and is formed with either 1,4 or 1,6 α-bonds, and depending on the ratio can result in its two main polymers, amylose and amylopectin. Amylose is a near linear polymer composed almost entirely of α-1,4 bonds, and amylopectin is a highly branched polymer composed mostly of α-1,4 bonds chains, and numerous α-1,6 bond branching points (Banks and Muir, 1980; Moran Jr., 1982; Smith, 2001; Carre, 2003; Tester et al., 2004a; Tester et al., 2004b). Major properties of these two polymers of glucose are shown in table 1.1. Amylose has the ability to form a double-helix (Moran Jr., 1982), and can form complexes with lipids (Tester et al., 2004a). Whereas amylopectin forms a cluster-like arraignment, these different structures aid in forming starch granules (Smith, 2001).

Glucose Polymer Formation

Both polymers of glucose both start from the same source, sucrose (Smith, 2001; Tester et al., 2004a). Sucrose is broken down into uridine diphosphate glucose (UDP-glucose) and fructose via sucrose synthase (Tester et al., 2004a). UDP-glucose is then converted into glucose-1-phosphate by UDP-glucose pyrophorylase. In cereal grains glucose-1-phosphate is converted into ADP-glucose in the cytosol, and then transported into the plastid or amyloplast for conversion into starch (Smith, 2001). Once in the amyloplast, different enzymes used in synthesizing starch will determine which polymer is formed, amylose or amylopectin.

There are two basic enzymes of starch synthesis, starch synthase and starch branching enzyme, and there are different isoforms of each enzyme determine which starch polymer is formed (Smith, 2001). There are four distinct isoforms of starch synthase, GBSS (granule bound starch synthase), SSI, SSII and SSIII, and two starch branching isoforms SBEA and SBEB. For amylopectin synthesis it is thought that SSII and SSIII are the important starch synthase enzymes, along with starch branching enzymes, SBEA and SBEB. SSII and SSIII form the chains of the branches, and combined with SBEA and SBEB form a pre-amylopectin polymer. This form of amylopectin is not sufficiently organized to form a granule, and is trimmed by starch debranching enzymes, or isoamylase, allowing the formation of an organized amylopectin polymer. Amylose synthesis relies on GBSSI, and the lack of this enzyme causes a “waxy” (almost pure amylopectin) starch formation. In normal corn starch these two polymers interact to form a starch granule.

Granule Formation

Cereal grains store starch in the form of a granule, and starch granules are composed of the two main polymers of starch, amylose and amylopectin, which comprise 98-99% of the dry weight (Tester et al., 2004a). Different chain lengths of amylopectin branches, their distribution and clusters, create a semicrystalline matrix in the granule (Smith, 2001). Adjacent chains form double helices within clusters, creating the crystalline lamellae, whereas amorphous lamellae are formed between branching points of the amylopectin, the difference between the lamellae is 9 nm (Smith, 2001; Tester et al., 2004a). Both crystalline and amorphous lamellae alternate to form crystalline zones. Alternating amorphous and crystalline zones create growth rings. Formation of starch granules and growth rings are displayed in figure 1.1.

Amylose and amylopectin interact to create starch granules particular crystalline structure (Tester et al., 2004a). Cereal starches have an A-type crystalline structure, whereas potato starch has a B-type crystalline structure (Banks and Muir, 1980; Moran Jr., 1982; Tester et al., 2004a; Tester et al., 2004b). A-type structure has a uniform distribution of water, which affects swelling properties of starch granules, and is displayed in figure 1.2. Normal corn starch granules contain between 20-35% amylose, with the rest being amylopectin (Cluskey et al., 1980; Tester et al., 2004a). Corn starch granules are between 2 to 30 µm (Tester et al., 2004a), with Cluskey et al. (1980) reporting an average of 11 µm. Cereal starches contain lipids which can bind to amylose in starch granules, but only compose ~1% (Tester et al., 2004a).

Starch Gelatinization

Modern day feed processing for broiler starter diets involves pelleting and crumbling. This introduces heat and water into the mash diet, allowing for the potential of gelatinization. Gelatinization can only fully occur when sufficient heat and water are present. Gelatinization is defined as the swelling of starch granules with the addition of heat and water, when the temperature increases the granule loses its organized form, and with continued heating the process cannot be reversed (Banks and Muir, 1980; Tester et al., 2004b). When sufficient water is present the process is complete at 75 ^{o}C (Tester et al., 2004b). Onset of gelatinization in excess water is ~45 ^{o}C, but this will be higher without sufficient water. Lower moisture levels require higher temperature for gelatinization. Meaning in insufficient moisture scenarios, some granules will gelatinize, but not all. When cereal starch gelatinizes, the granules tend to swell and not burst (Banks and Muir, 1980). This swelling of the granule will increase the viscosity of the starch solution, high viscosity is widely considered to have a negative effect on efficient digestion.

Starch Digestion

When a broiler chick consumes feed, a chick first picks up the feed with its beak and then raises its head to move the feed down the esophagus. After feed passes down the esophagus, it enters the crop, where starch granules are exposed to moisture. This exposure to moisture will cause starch granules to swell (Banks and Muir, 1980). Unlike mammals chickens contain no salivary amylase, thus the first exposure to enzymatic hydrolyzation will occur in the small intestine (Moran Jr., 1982). Amylase produced in a chicken's pancreas is called α-amylase. Pancreatic α-amylase has the ability to degrade intact starch granules (Banks and Muir, 1980). Enzymatic degradation in cereal grain A-type starch granules results in extensive erosion and fragmentation. Due to limited access to starch granules, α-amylase attacks a limited area instead of spreading throughout the entire granule. The mode of action of α-amylase is to attack the amylose or amylopectin from the non-reducing end, cleaving off a maltose unit (Moran Jr., 1982). In a starch granule pancreatic α-amylase hydrolyzes interior α-1,4 bonds, and products of enzymatic hydrolysis are simple sugars, maltose, maltotriose and isomaltose (Carre, 2003). Products of α-amylase degredation can pass through the unstirred water area and glycocalyx of the small intestine. When simple sugars reach the intestinal epithelium, they are hydrolyzed by either maltase or sucrase-isomaltase into glucose (Moran Jr., 1985). Maltase hydrolyzes maltose or maltotriose, and sucrase-isomaltase hydrolyzes sucrose or isomaltose. Glucose enters enterocytes using a Na^+ -dependent transporter, and is passed into the blood stream in enabling conversion of glucose into energy for growth and maintenance.

The chick's digestive process described above is very efficient. Research has been conducted showing digestibility of starch in a depancreatized chicken was 72% compared to 97% in an intact chicken (Ariyoshi et al., 1964). This high digestibility has been confirmed in more recent research. Uni et al. (1995b) reported starch digestibility of 90-95%, depending on age, whereas Noy and Sklan (1995) reported an ileal digestibility of corn starch of 82-89%. Ground corn displayed similar high digestibility of 97% for 4 week old broilers (Weurding et al., 2001) and wheat starch digestibility from ground wheat has been reported to be 77% (Svihus and Hetland, 2001). All of these values show a high percentage of the glucose consumed in the form of starch being absorbed by the chicken intestinal tract.

Chicken Small Intestine

Main concern of this literature review is absorption and utilization of nutrients, and specifically starch. This takes place in the small intestine of the chicken which has a defined structure. The small intestine is divided into three segments, the duodenum, jejunum, and ileum. Each section has different absorption and enzymatic hydrolysis values, which will be discussed in the next section of the review. Small intestinal epithelium contains numerous villi, which are fingerlike projections from the intestinal wall (Moran Jr., 1985). An intestinal villus contains enterocytes, the cells responsible for nutrient absorption. To aid in absorption of nutrients enterocytes have microvilli, small finger like projections, and these further increase surface area. These microvilli and glycocalyx can clearly be seen in electron micrographs (Humphrey and Turk, 1974). The glycocalyx is a glycoprotein web formed by enterocytes and is where the brush border enzymes are located. Villi glycocalyx aids in preventing damage to enterocytes and traps nutrients for absorption, and in chickens the glycocalyx is thinner, which is believed to be caused by extensive peristaltic action (Moran Jr., 1985).

Chick Growth and Development of the Gastrointestinal Tract

Chicks begin life in an egg, and have an incubation period of 21 days. On the 21st day the chick hatches, and in a commercial broiler operation, is shipped to grow out houses where chicks will start to consume feed. Broiler chicks grow quickly doubling in size by day 6 and having another two-fold increase by day 11 (Nitsan et al., 1991a), this means chicks will grow from 45 g on day 0 and reach 400 g by day 21 (Noy and Sklan, 1995). Rapid growth of broiler chicks suggests a rapidly developing digestive tract in order to absorb sufficient nutrients.

Gastrointestinal Growth

Rapidly developing digestive tract in meat type chickens has been found to increase in length by 5% from 10 to 21 days of age (Newcombe and Summers, 1984). Cornish x Rock cross chicks had an increase in small intestinal length by a factor of 3.45 (reported in mm) (Obst and Diamond, 1992). During the same growth period small intestinal weight increased by 15 fold.

Rapid growth in intestinal weight was observed in earlier research to increase in relative weight from 0-8 days of age (Dror et al., 1977). Nitsan et al. (1991a) found a 10-fold increase in small intestinal weight by day 8 and 20 fold increase by day 23. In broiler breeder males this increase in intestinal weight was shown to increase relative to body weight during the first 6 days, after day 6 intestinal weight decreased relative to body weight (Nitsan et al., 1991b). This increase in relative intestinal weight was not reflected in the gizzard, where it decreased from day 0 in relation to body weight. Nir et al. (1993) observed an increase in gastrointestinal tract mass throughout the experiment, and small intestinal relative weight gain peaked at day 5. Increase in relatively weight gain of the small intestine during the first week is supported in a review conducted by (Sklan, 2001).

Intestinal Development

This increase in small intestinal mass and length is supported by small intestinal epithelium development. Villi increase intestinal surface area, which will increase intestinal absorptive capacity. Uni et al. (1995a) found increases in villi height and perimeter from day 0 to day 5, and by day 7 villi are almost double in height and perimeter. Intestinal crypts are found to double during the same time period. Crypts of the small intestine are where enterocytes are produced, and crypt depth is in important for maintenance of small intestinal epithelium. Rapid increase in height is supported by Uni et al. (1995b), where villus height and perimeter increased 25 to 100% between 4 and 10 days of age. As villi increase in height and perimeter, villi number per area decreases, this decrease is countered with an increase in villus volume. Greatest increase in jejuna and ilea volume was observed to occur from 7 to 10 days of age. Increases in jejuna villus volume has been observed to greatest from 7 to 14 days of age, whereas duodena villi increase was complete by 7 days of age (Uni et al., 1998). No increase was seen in the first

2 days of life for any of the segments. Research presented also confirmed the increase in crypt depth in the intestine, which was found to be two to three fold over the first 14 days of post hatching.

During the same early developmental period, where villi are rapidly growing and developing, microvilli increase in size. Microvilli start to form *in ovo*, and grow and mature rapidly within the first week of life (Chambers and Grey, 1979). This aids in increasing villus total volume, as previously stated. Elongations of the microvilli are part of the transformation of villi from immature at hatching, to mature within the first week. Bayer et al., (1975) describes duodena villi of day old chicks as relatively smooth, and by 7 days of age villi have a more complex form. This complex form contains folds and recesses, increasing small intestinal surface area. Jejuna and ilea villi have similar mature characteristics as duodena villi at one week of age. This extra surface area will increase intestinal absorptive capacity of nutrients hydrolyzed by digestive enzymes.

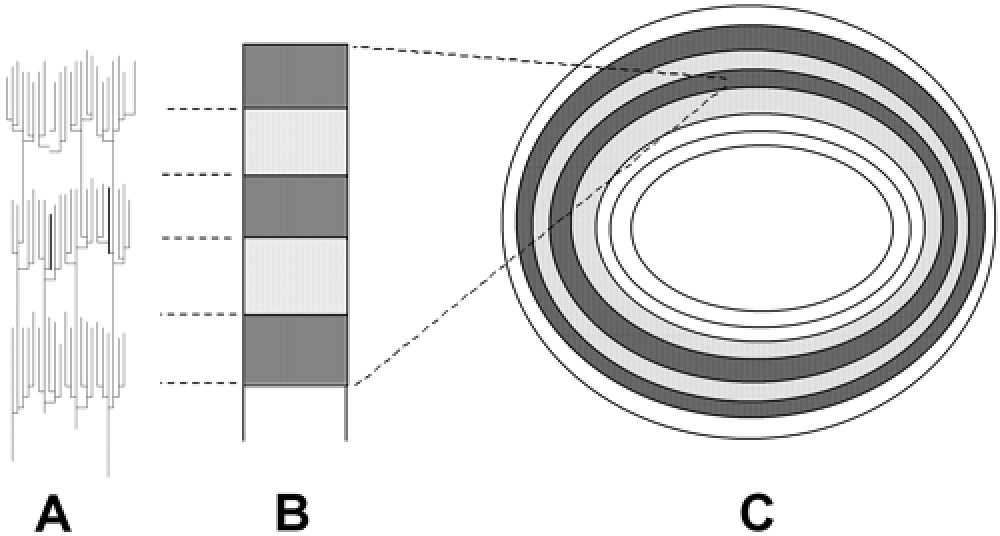
Enzyme Development

In order for chicks to utilize the increase in small intestinal absorptive capacity, enzymatic hydrolysis of digesta increases. Pancreatic production of α-amylase begins before hatching, with a sharp increase in the days leading up to hatching (Marchaim and Kulka, 1967). Observed increases in α-amylase in chick’s pancreas, pre- and post-hatching leads to an increase in the amount found in chick’s intestinal tract. Amylase secretion into the intestine was observed to increase by 100-fold from 4 to 21 days of age (Noy and Sklan, 1995). Increased secretion of α-amylase had no effect on starch digestibility remaining between 82 to 89%. Since chicks are observed to grow both in total body weight and intestinal weight, demand for amylase increases. Increased activity of α-amylase has been observed to be affected by feed intake within the first 4 days. Chicks who received feed demonstrated higher α-amylase activities than chicks without access to feed (Sklan and Noy, 2000). Both sets of chicks had increased amylase activity by 7 days of age, and chicks without access to feed demonstrate a rapid increase in amylase activity once feed was provided.

Activity of α-amylase is not equal across the sections of the intestine. The pancreatic duct is at the start of the jejunum, and the jejunum is where activity of pancreatic α-amylase was shown to be highest (Osman, 1982). Activity of amylase in intestinal tissue was observed to be highest in the duodenum, demonstrating potential for degradation of starch granules in the duodenum. Optimum pHs were determined for the different enzymes, and were found to be 7.5 for pancreatic amylase and 6.9 for the intestinal amylase. A comparison of concentrations of α-amylase activity in the pancreas revealed chickens concentration of amylase activity to be higher than numbers reported for cattle, camels and pigs. Since α-amylase does not break down starch into glucose, disaccharidases increase during the corresponding time period. These enzymes are closely correlated with villus enterocytes number in all regions of the intestine after the 2 days of age (Sklan, 2001). Relative secretion per enterocytes was maintained after 2 days of age, and there was no increase observed.

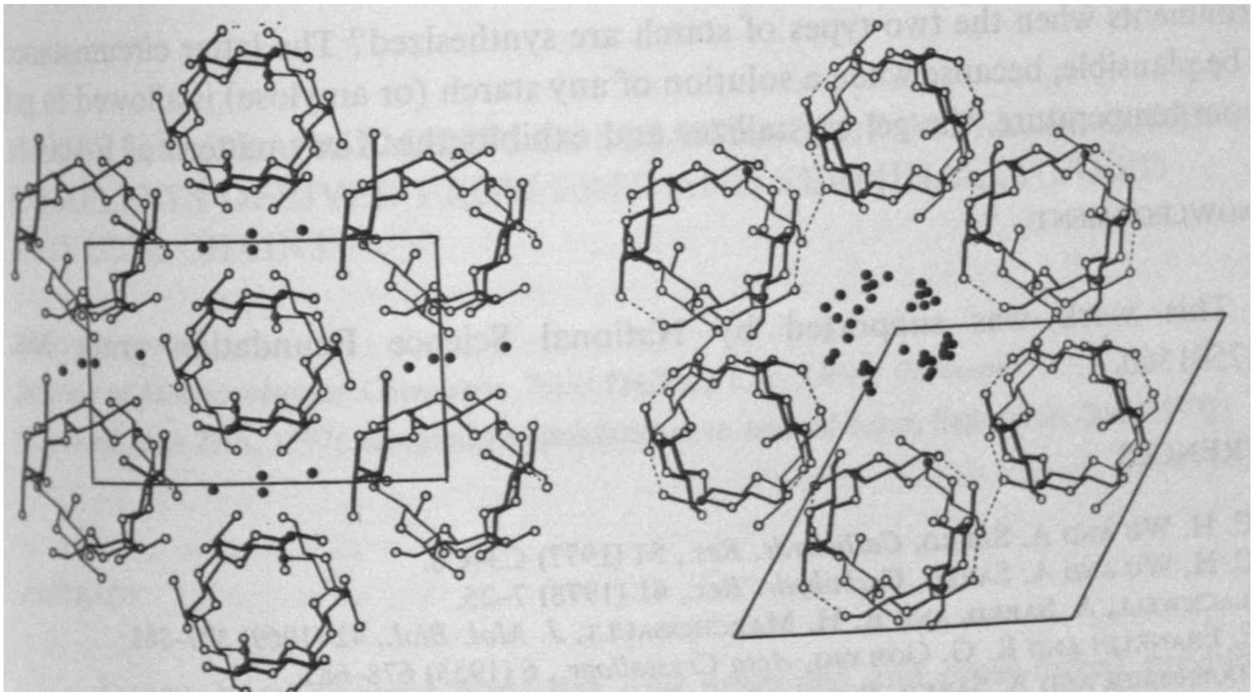
Modern meat-type commercial chicks now grow faster and more efficiently through genetic selection. A comparison between a genetic line from 1972 and one from 1990 showed an almost 80% increase in six week body weight (Mitchell and Smith, 1991). This increased gain was supported by an intestinal weight of almost double, and an increase of villi surface area of 1.5 to 1.8 fold. This large increase in growth over the past 30 years has emphasized the need for efficient feed conversion. Literature reviewed has shown potential for current feed processing technology to alter broiler diets, demonstrated starch granule complexity, formation, enzymatic degradation, and rapid gastrointestinal growth and development of modern commercial broiler chicks.

Figure 1.1 Starch Granule Formation and Structure



The organization of amylopectin to form starch granule. The shorter chains of the amylopectin molecule are clustered together at intervals of 9 nm along the axis of the molecules (A). Within a cluster, adjacent form double helices. These pack together in a regular manner to form crystalline lamellae, which alternate with amorphous lamellae where the branch points are located (B). Within the granule, zones of alternating amorphous and crystalline lamellae themselves alternate with amorphous zones, forming “growth rings” several hundreds of nanometers in width (C). (A.M. Smith, 2001)

Figure 1.2 Structure of Crystalline Amylose



The structure on the left is the A-type crystalline amylose. The water is distributed evenly in the crystalline structure. This is the structure used by cereal starches. The structure on the right is the B-type crystalline amylose. The water is concentrated in the center of the crystalline structure. This structure is used by potato starches. (H.C.H Wu and A. Sarko, 1978)

Table 1.1 Major Properties of the Starch Components

Major Properties	Amylose	Amylopectin
Molecular Configuration	Essentially Linear	Highly branched
Average Molecular Weight	10^6	10^8
X-Ray Diffraction	Crystalline	Amorphous
Complex Formation	Readily forms complexes with iodine and polar substances	Very limited complex formation
Stability in aqueous solution	Unstable, tends to retrograde	Stable

Shows the physical property differences between the two main polymers of glucose (W. Banks and D.D. Muir, 1980)

CHAPTER 2 - Effects of Feeding Diets with Different Levels of Gelatinized Starch on Growth Performance of Broilers during the Starter Period

Abstract

To determine the effects of processing commercial broiler diets with heat and moisture we conducted two experiments. To simulate the effects of starch gelatinization in a broiler diet we used a combination of conventional corn starch and pregelatinized unmodified corn starch. Experimental diets were fed from d 0 to 21, to observe effects on early chick growth. In experiment 1 the inclusion of pregelatinized starch ranged from 0 to 35% of total diet, increasing in increments of 5%. Using results from experiment 1, experiment 2 was designed with a range from 0 to 21% of total diet as pregelatinized starch with an incremental increase of 3%. Results from both experiments demonstrated a negative effect of increased inclusion of pregelatinized starch inclusion on bird live weight gain and feed:gain. Highest live weight gain in both experiments was in the conventional corn starch only diet. In both experiments 1 and 2, the 0% diet was statistically different (*P*<0.05) from diets with minimal inclusion of pregelatinized starch (5% and 3%). Lowest feed:gain were observed in the 0 and 5% diets in experiment 1, and 0 to 15% diets in experiment 2 (*P*<0.05). In experiment 1, increase in feed:gain was a result of decreased body weight gain. In experiment 2, the 21% diet had higher feed consumption than the 6 to 15% diets (*P*<0.05). There were no differences observed in mortality between treatments. Gelatinization of starch is shown to have a negative effect on feed efficiency and chick live weight gain.

Key words: starch, gelatinization, chick, growth performance

Introduction

Modern broiler diets consist primarily of corn and soybean meal and are pelleted using steam conditioning. Evidence of feeding a pelleted on improving broiler growth performance is overwhelming. Pelleting increases moisture and temperature through steam conditioning and die friction. Given sufficient heat and moisture starch granules in corn will gelatinize (Tester et al., 2004b). Gelatinization is described as a transformation from an organized crystalline structure, to one without an organized crystalline structure. Stated values for gelatinization with excess water were between 60-75 ^{o}C, and higher heat is required for complete gelatinization with lower amounts of water. Hussar and Robblee (1962) observed after 45 minutes of operation, a pellet mill can produce pellets with a temperature of 69 ^{o}C . The temperatures cited could produce a feed with at least partial gelatinization. With this loss of the crystalline structure it is generally believed that this will be beneficial to the digestion of starch (Tester et al., 2004b). There is some evidence to the contrary since Cramer et al. (2003) found that expanded, highly gelatinized diets had no improvement over conventional pelleting, even with higher pellet quality. Gain:feed has been demonstrated to decrease with increases in highly gelatinized extruded corn (Moritz et al., 2005). Batal and Parsons (2004) investigated the effects of different carbohydrate sources and observed higher live weight gain and gain:feed with conventional corn starch when compared to unmodified pregelatinized corn starch.

With evidence demonstrating that processing starch with heat and moisture may not be beneficial to broilers, a series of two experiments were designed. The first was designed over a broad scope to observe the effects of graded levels of gelatinized starch. The second experiment expanded on the conclusions of the first experiment, and narrowed the range of gelatinization.

Materials and Methods

General Procedures

The Kansas State University Institution of Animal Care and Use committee approved all experimental procedures. Both experiments were conducted using day old Cobb 500 (Cobb-Vantress, Siloam Springs, AR) male chicks. Chicks were housed in Petersime batteries (Petersime Incubator Co., Gettysburg, OH), at the Thomas B. Avery Poultry Research Unit (Manhattan, KS). Upon arrival at the facility all chicks were weighed and placed in the pens. In both experiments there were eight chicks per pen, and eight replicates per diet. Diets were formulated to meet or exceed nutrient concentrations recommended by the NRC (1994), and are displayed in table 2.1. Diets used conventional corn starch, and pregelatinized unmodified corn starch (product number 12030, Cargill Foods, Minneapolis, MN), and the variable was the level of each in the diet. Chicks were grown from d 0 to 21 with feed and water provided ad libitum. Deceased birds were removed and weighed as necessary. On d 21 both feed and bird weight was recorded. Broiler live weight gain (**LWG**), pen feed consumption, and feed:gain (**F:G**) were calculated using these values. F:G included mortality weight.

Experiment 1

The objective of experiment 1 was to establish a range of gelatinization that is beneficial to chick growth and feed efficiency and utilized a complete randomized design. Diets varied in inclusion of pregelatinized starch from 0 – 35% of the diet, increasing in increments of 5%, and the corn starch started at 47% and decreased by 5% increments to 12%. Different levels of pregelatinized starch were designed to simulate a broad range of gelatinization levels.

Experiment 2

Experiment 2 was designed using the results from the first experiment. Objective of this experiment was to narrow the range of gelatinization, in order to improve understanding of the effects gelatinization has on broiler growth performance. This experiment utilized a randomized complete block design. Inclusion of the pregelatinized starch was lower in this experiment and ranged from 0 to 21 % with increments of 3%. Corn starch started at 47% and decreased by 3% increments to 26%.

Statistical Analysis

Live weight gain, pen consumption, mortality and F:G were analyzed using the GLM procedure in SAS (Release 9.1 for Windows, SAS Institute, Cary, NC) . Fisher's least significance difference tests were performed to separate means when F values showed significance. Data were analyzed using the MIXED procedure for potential polynomial relationships in each experiment.

Results

Experiment 1

Increased inclusion of pregelatinized starch demonstrated a negative effect on LWG (table 2.2, $P<0.001$). LWG was highest at the 0% inclusion level, or corn starch only diet, and was significantly different than the 5% diet (467 vs. 411 g, $P<0.05$). The 5% diet had higher LWG than the 10% diet (411 vs. 341 g, $P<0.05$), and there was no difference between the 10-35% diets ($P>0.05$). Pen feed consumption and inclusion of pregelatinized starch exhibited an interaction (table 2.2, $P<0.003$). A difference existed between the 0% and 10% diet (5.405 vs. 4.490 kg, $P<0.05$). The 5% diet had a higher pen feed consumption than the 25 and 35% diets (4.915 vs. 4.306 and 4.301 kg, $P<0.05$). The 10 to 20% and 30% diets had similar pen feed consumptions (*P*>0.05). Inclusion rate was observed to have a negative effect on F:G (table 2.2, *P*<0.0126), The 5% diet was lower than the 10% diet (1.48 vs. 1.79, *P*<0.05), and the 0 and 5% diets were lower from the 15-35% diets (*P*<0.05). There was no interaction observed between inclusion rate and mortality (*P*>0.10), the difference between percent mortality were large but this was due to limited numbers of birds per pen. Increased inclusion of pregelatinized starch was observed to have a negative quadratic effect (table 2.4, *P*<0.001) on LWG. F:G and inclusion level were observed to have a positive linear relationship (table 2.4, *P*<0.001).

Experiment 2

Similar to experiment 1 increased inclusion rate demonstrated a negative effect on LWG (table 2.3, *P*<0.001). The 0% diet had the highest LWG (457 g), and was significantly different than 3-21% diets (*P*<0.05). The 3% diet (410 g) was higher than the 15-21% diets, and the 6% diet (394 g) was higher than the 18 and 21% diet (*P*<0.05). Pen feed consumption demonstrated an interaction with inclusion level (table 2.3, *P*<0.001). The 0% diet (5.702 kg) had higher pen feed consumptions than the 3-21% diets (*P*<0.05). The 3% diet (5.076 kg) and 21% diet (5.57 kg) pen feed consumption was higher than the 6, 9 and 15% diets (*P*<0.05). F:G was observed to have an interaction with inclusion level of pregelatinized starch (table 2.3, *P*<0.001). The 18 and 21% F:G's (1.904 and 1.896, respectively) were significantly higher than the 0-15% (*P*<0.05). In agreement with Experiment 1, there was no effect on chick mortality by treatment, and the high percent mortality was again due to low numbers of chicks per cage. LWG and inclusion level of pregelatinized starch demonstrated a negative linear relationship (table 2.5, *P*<0.001). F:G and inclusion level of pregelatinized starch were observed to have a positive quadratic relationship (table 2.5, *P*<0.016).

Discussion

All diets had a negative effect on bird growth, and when compared to NRC values the diets with highest LWG were around 200 g lower. The diets tended to adhere to the beaks, and this could be part of the reason for the depressed LWG when compared to the NRC. After adjusting for feed texture, increases in pregelatinized starch still had a negative effect on LWG and F:G. Experiment 2 had a high pen feed consumption with the 21% diet, and in experiment 1 there was no significant difference between the 35% and the 10% diets ($P<0.05$). With no difference observed in pen feed consumption with higher inclusion rates of pregelatinized starch, the possibility of feed texture causing the negative effects on LWG and F:G is limited.

LWG demonstrates a negative relationship with higher amounts of pregelatinized starch, and these results are in agreement with Batal and Parsons (2004), who found a decrease in LWG and feed efficiency. Decrease in feed efficiency observed in this research is in agreement with results observed using extrusion processing to increase gelatinization level (Moritz et al., 2005). Increase in gelatinization having a negative effect on feed efficiency was supported by Moritz et al. (2001), where increased gelatinization level was caused by moisture addition to the mash prior to pelleting. Gonzalez-Alvarado et al. (2007) contradicts the results of this research and previously stated research with no statistical difference shown between the unprocessed corn and heat processed corn. Decreased chick growth and feed efficiency demonstrated with increased levels of gelatinization could explain the results in (Cramer et al., 2003). Different pellet qualities in the diets could have reduced the negative effect of increased gelatinized starch. Effect of pellet quality and starch gelatinization is not supported by Moritz et al. (2003), where they are not seemingly correlated. Diets with different levels of gelatinization have similar feed efficiencies, but the pellet qualities are not significantly different. No observed differences between pellet qualities could be the reason for no observed effect of starch gelatinization.

Polynomial regression analysis resulted in conflicting results. In experiment 1 a quadratic relationship was observed between LWG and inclusion level, whereas in experiment 2 this was found to be linear. F:G demonstrated a linear relationship in experiment 1 and quadratic relationship in experiment 2. A possible reason for different regression results could be due to different inclusion levels between experiments. Lower levels of inclusion in experiment 2 limited the range of observed effects and changed regression relationships.

Research on starch gelatinization has been inconclusive, but does demonstrate the possibility of increased levels of starch gelatinization decreasing broiler growth performance. No observed differences in growth performance in diets with different pellet qualities and results of purified carbohydrate diets suggest a negative correlation between starch gelatinization and broiler growth performance. This is supported by the conclusions of the this research, where regression analysis demonstrated negative linear and quadratic relationships on LWG and F:G with increased gelatinized starch. More research does need to be conducted in this particular area, specifically without a purified carbohydrate due to concerns over feed texture.

ACKNOWLEDGEMENTS

The authors would like to thank Robert Beckley, Robert Resser, Rebecca Madsen, and Elizabeth Beilke for their help with the set-up and ending of the experiments.

Table 2.1 Diet for Experiment 1 and 2

Ingredients	% in Diet
Corn starch/Pregelatinized starch	47.04
Soybean meal (48%)	40.10
Soy oil	7.20
Limestone	1.52
Dicalcium phosphate	2.03
Salt	0.46
DL-Methionine	0.20
Feed additives[123]	1.35
Lysine	0.07
Calculated Composition	
Metabolizable energy (kcal/kg)	3200
Crude protein (%)	23
Lysine (%)	1.37
Methionine (%)	0.55
Tryptophan (%)	0.32
Threonine (%)	0.88
Calcium (%)	1.10
Available Phosphorus (%)	0.50
Sodium (%)	0.20

[1] Supplied at per kilogram of diet manganese, 0.02%; zinc, 0.02%; iron, 0.01%; copper, 0.0025%; iodine, 0.0003%; selenium, 0.00003%; folic acid, 0.69 mg, choline, 386 mg; riboflavin, 6.61 mg; biotin, 0.03 mg; vitamin B_6, 1.38 mg; niacin, 27.56 mg; panthothenic acid, 6.61 mg; thiamine, 2.20 mg; menadione, 0.83 mg; vitamin B_{12}, 0.01 mg; vitamin E, 16.53 IU, vitamin D_3, 2,133 ICU, vitamin A, 7,716 IU.

[2] Celite 281, Celite Corporation, Lompoc, California

[3] Virginiamycin, 20 g/lb (2 lb/ton inclusion rate), Phibro Animal Health

Table 2.2 Growth Performance Data from Experiment 1

% Inclusion of Pregelatinized Starch	Live Weight Gain (g)	Pen Feed Consumption (kg)	F:G[1] (kg feed:kg gain)	Mortality (%)
0	467^{a}	5.405^{a}	1.529^{ab}	9.38
5	411^{b}	4.915^{ab}	1.478^{a}	10.94
10	341^{c}	4.490^{bc}	1.787^{bc}	9.38
15	314^{c}	4.321^{bc}	1.870^{c}	7.81
20	308^{c}	4.3521^{bc}	1.889^{c}	12.50
25	307^{c}	4.306^{c}	1.888^{c}	12.50
30	0.320^{c}	4.506^{bc}	1.866^{c}	7.81
35	0.305^{c}	4.301^{c}	1.900^{c}	7.81
P-value	<0.001	0.003	0.012	0.307
SEM (n=8)	0.017	0.207	0.101	0.966

[a,b,c] Means within a column with different superscripts are significantly different ($P<0.05$)

[1] Adjusted for mortality

Table 2.3 Growth Performance from Experiment 2

% Inclusion of Pregelatinized Starch	Live Weight Gain (g)	Pen Feed Consumption (kg)	F:G (kg feed:kg gain)^1	Mortality (%)
0	457^{a}	5.702^{a}	1.656^{a}	9.38
3	410^{b}	5.076^{bd}	1.591^{a}	9.38
6	394^{bc}	4.499^{c}	1.660^{a}	17.19
9	389^{bcd}	4.386^{c}	1.619^{a}	12.50
12	372^{bcde}	4.759^{cd}	1.735^{a}	12.05
15	362^{cde}	4.651^{c}	1.625^{a}	4.69
18	341^{e}	4.916^{cd}	1.904^{b}	12.50
21	350^{de}	5.57^{d}	1.896^{b}	12.50
P-value	<0.001	<0.001	<0.001	0.740
SEM (n=8)	0.016	0.204	0.054	0.36

$^{a-e}$ Means within a column with different superscripts are significantly different ($P<0.05$)

[1] Adjusted for mortality

Table 2.4 Polynomial Regression for Experiment 1

LWG	*P*-value	R^2	β_0	β_1	β_2	β_3	β_4
Linear	<0.001	0.602	0.41714	-0.00404	-	-	-
Quadratic	<0.001	0.602	0.46212	-0.01304	0.000257	-	-
Cubic	0.133	0.602	0.473	-0.01886	0.000701	-8.46×10^{-6}	-
Quartic	0.264	0.602	0.4681	-0.01185	-0.000336	3.93×10^{-5}	-6.83×10^{-7}
F:G							
Linear	<0.001	0.271	1.57343	0.01156	-	-	-
Quadratic	0.070	0.271	1.47046	0.03216	-0.000588	-	-
Cubic	0.944	0.271	1.47353	0.03055	-0.000466	-2.34×10^{-6}	-
Quartic	0.196	0.271	1.5115	-0.02135	0.00722	-0.000358	5.06×10^{-6}

Table 2.5 Polynomial Regression for Experiment 2

LWG	*P*-value	R^2	β_0	β_1	β_2	β_3	β_4
Linear	<0.001	0.493	0.43494	-0.00482	-	-	-
Quadratic	0.089	0.493	0.44868	-0.0094	0.000218	-	-
Cubic	0.591	0.493	0.4521	-0.01239	0.000598	-1.21×10^{-5}	-
Quartic	0.213	0.493	0.45733	-0.02429	0.00354	-0.000238	5.38×10^{-6}
F:G							
Linear	<0.001	0.419	1.57492	0.01293	-	-	-
Quadratic	0.016	0.419	1.64745	-0.01125	0.001125	-	-
Cubic	0.992	0.419	1.64722	-0.01104	0.00113	8.14×10^{-7}	-
Quartic	0.858	0.419	1.64447	-0.00479	-0.00042	0.000119	-2.83×10^{-6}

CHAPTER 3 - Effects of Corn Particle Size and Gelatinized Starch on Broiler Growth Performance during the Starter Period

Abstract

Two main practices of current feed manufacturing are grinding cereal grains, and processing the diet through a pellet mill, which involves heat and steam. To investigate the effects of these two factors and the possibility of their interaction an experiment was conducted. Experimental design was a 3 x 3 factorial arrangement of treatments with three different particle sizes (466 µm, 878 µm, and 1240 µm), and three gelatinization levels (0%, 10% and 20%). Corn was ground to three different sizes using a roller mill, and to simulate the levels of gelatinization 20% of the starch provided by the corn in starter diet was replaced by conventional corn starch or unmodified pregelatinized corn starch. The 0% level of gelatinization contained only conventional corn starch, 10% was a blend of conventional corn starch to pregelatinized corn starch in a 1:1 ratio, and the 20% level contained only pregelatinized corn starch. Diets were fed during the starter period, 0 to 21 d. Gelatinization demonstrated an effect on live weight gain ($P<0.0177$), with the 20% being lower than the 0% and 10% ($P<0.05$). There was an interaction of feed:gain and gelatinization level ($P<0.0218$), and the 0% feed:gain was lower than the 20% feed:gain ($P<0.05$). Particle size demonstrated an effect on live weight gain ($P<0.0038$), with the medium and large particle size had higher live weight gains than the small particle size ($P<0.05$). Pen feed consumption was lower for the small versus the medium and large particle size ($P<0.05$). There was no interaction between the gelatinization level and particle size for any of the measurements ($P>0.10$). Overall the two larger particle sizes and the two lower gelatinization levels had higher body weight gains, and the lowest gelatinization level demonstrated lower feed:gain.

Keywords: chick, starch, gelatinization, particle size

INTRODUCTION

Current feed manufacturing methods involve grinding of cereal grains, and pelleting the whole diet. These two factors can change a broiler chicks live weight gain, and feed efficiency. Grinding size of cereal grains, usually corn, can be altered and has been shown to have an effect on bird live weight gain, and feed efficiency. Reece et al. (1986) observed diets formulated with corn ground to 1289 µm and 679 µm demonstrated similar growth and efficiency while a particle size of 987 µm displayed poorer growth performance. This was contradicted by Nir et al. (1994b) who concluded the best performing particle size was 897 µm during the starter period. In follow up experiments 1130 µm grind size displayed better growth performance (Nir et al., 1994a). These results were supported by Parsons et al. (2006), where the best growth performance was corn ground in range from 781 to 1109 µm. There has been some evidence showing particle sizes between 900 – 1700 µm can produce similar results to 600 µm particle size. This is a sampling of literature published on the subject of particle size, and has revealed some varied results. Use of a larger particle size may be beneficial or not detrimental to live weight gain and feed efficiency of broiler chicks.

The process of pelleting involves steam conditioning, and friction in the die as pellets are formed. These two actions add heat and moisture to broiler diets. This can affect cereal grain starch granules. Addition of heat and water to starch granules in sufficient quantities will cause the granules to swell and gelatinize (Banks and Muir, 1980). Pelleting generates sufficient heat for gelatinization, but since moisture is limiting gelatinization will be incomplete (Hussar and Robblee, 1962; Tester et al., 2004b). Gelatinization levels in a pellet can vary with dietary ingredients and formulation, and have been observed to vary from 1 to 19% (Svihus et al., 2004). A survey of published literature revealed levels from 5 to 25% in pelleted diets, deomstrating potential for variation (Moritz et al., 2001; Cramer et al., 2003; Moritz et al., 2003; Svihus et al., 2004). These levels of gelatinization have met with mixed results, with Cramer et al. (2003) showing no difference between the high and low gelatinized diet, even with different pellet durability's. These results were supported by Moritz et al. (2001), where higher gelatinized diets were similar to lower gelatinized diets, and both had similar pellet qualities.

An experiment was designed to find out what these effects when combined would have on bird weight gain and feed efficiency. In order to eliminate possible benefits of having feed in pelleted form all of diets were mash.

MATERIALS AND METHODS

All animals were reared following protocols established by the Kansas State University Institution of Animal Care and Use Committee.

Corn Grinding and Diet Composition

Corn was ground to three particle sizes (**PS**), small particle (**SP**), medium particle (**MP**) and large particle (**LP**), using a three-high roller mill (Model K, Roskamp Manufacturing, Cedar Rapids, IA) at the K-State Grain Science Feed Mill (Manhattan, KS), to a target of 400-500 µm, 800-900 µm, and 1200-1300 µm. These grind sizes were chosen to represent a finer grind than industry, industry standard, and coarser than industry standard grind. Samples were taken from the roller mill, and where corn was bagged to ensure targeted particle size was achieved. These samples were analyzed individually at the mill, and later screen weights were pooled together to find mean particle size of the corn. Particle size was determined using a Tyler Rotap (Mentor, OH), and using U.S. standard size 6-270 screens. In order to simulate gelatinization levels found in pelleted diets a calculation was performed to find percentage of corn starch in a typical NRC diet. Using this value a diet was formulated where 20% of starch provided by ground corn was replaced with conventional corn starch or unmodified pregelatinized corn starch (product number 12030, Cargill Foods, Minneapolis, MN). Blending the conventional corn starch and unmodified pregelatinized corn starch created three different levels of gelatinization, 0% (only conventional corn starch), 10% (1:1, conventional corn starch to unmodified pregelatinized corn starch), and 20% (only unmodified pregelatinized corn starch). These gelatinization levels were combined with the three different corn particle sizes to create a 3x3 factorial. Diets were formulated to meet or exceed NRC (1994) nutrient requirements (table 3.1).

Broiler Weight Gain and Feed Efficiency

Chicks were housed in a floor pen facility at the Thomas B. Avery Poultry Research Unit (Manhattan, KS). Experiment utilized a complete randomized block design. There were four blocks representing the NW, NE, SW, and SE portions of the building. There were nine experimental treatments with eight replications, two per block, utilizing 72 pens. Experiment started with day old Cobb 500 (Cobb-Vantress, Siloam Springs, AR) male broiler chicks. An average weight was taken for the chicks and they were placed 30 per pen. Feed was weighed, and recorded at the beginning of the experiment. Birds were provided feed and water ad libitum. Temperature was regulated at 35 ^{o}C (95 ^{o}F) on day 1, and decreased slowly to maximize bird comfort. Dead birds were removed and weighed as necessary. At 21 d feed and pen weights were recorded. Broiler live weight gain (**LWG**), pen feed consumption and feed to gain (**F:G**) were calculated. F:G included mortality weight.

Statistical Analysis

Data were analyzed using the GLM procedure of SAS (Release 9.1 for Windows, SAS Institute, Cary, NC). Experiment was analyzed as a randomized complete block design with a pen of broilers as the experimental unit. Fisher's least significance difference test was used to separate the means of treatments when F values showed significance. For all tests, $\alpha=0.05$.

RESULTS

Corn Grinding

Targeted range of the grind size was achieved for all treatments. Results of the particle size analysis are displayed in table 3.2. Resulting particle sizes of 465 µm, 877 µm, and 1240 µm, almost achieved the targeted distribution of particle sizes of 400 µm. Distributions of the particles within each grind are displayed in figures 3.1-3.3, and display a uniform particle size within each grind.

Chick Growth

Gelatinization Level

Increasing gelatinization level displayed a negative effect on LWG (table 3.3, $P<0.0178$). Highest weight gains were observed in the 0 and 10% level of gelatinization (0.769 and 0.773 kg respectively), and LWG's were significantly higher than the chick weight gain of the 20% diet (0.742 kg, $P<0.05$). Pen feed consumption was not affected ($P=0.623$) by gelatinization level, and only differed by approximately 300 g (table 3.3). Feed:gain was negatively affected by increased gelatinization level (table 3.3, $P<0.022$), and the 0 and 20% were significantly different (1.232 vs. 1.260, $P<0.05$). The effects on F:G were caused by increased weight gain, not increased feed intake. There was no effect on mortality by gelatinization level (table 3.3, $P=0.112$)

Particle Size

An effect on LWG by PS was observed (table 3.3, *P*<0.004). The SP diet had a smaller LWG than the MP or LP diets (0.739 kg vs. 0.779 and 0.767 kg, *P*<0.05), and the MP and LP had statistically similar LWG. Pen feed consumption displayed a similar relationship with PS as LWG (table 3.3, *P*<0.001). The SP had the lowest pen consumption (27.068 kg), and was significantly lower than the MP (28.792 kg, *P*<0.05). The LP's pen consumption (28.372 kg) was statistically similar to the MP and greater than the SP (*P*<0.05). No effect on F:G by PS was observed (table 3.3, *P*>0.10). Feed:gain were only numerically separated by 0.02 feed conversion points, and the SP and MP had the same mean (1.239). Similar gelatinization level no statistical correlation was found between particle size and mortality (table 3.3, *P*=0.131).

Interaction

There were no interactions observed between PS and gelatinization level on LWG (table 3.3, *P*=0.855). Pen feed consumption was not affected by interactions between PS and gelatinization level (table 3.3, *P*=0.726). No effects on F:G was observed by PS and gelatinization level interaction (table 3.3, *P*=0.837). Mortality was not affected by PS and gelatinization level interactions (table 3.3, *P*=0.382)

DISCUSSION

Increased level of starch gelatinization demonstrating a negative effect on LWG and F:G is in agreement with previous work done by this lab. Earlier work involved combining conventional corn starch and unmodified pregelatinized corn starch at different levels, and showed a significant decrease when pregelatinized starch was included as a low as 3% of the total diet. Results of this experiment could help explain no difference observed between treatments, an expanded diet with higher pellet quality and a normal pelleted diet (Cramer et al., 2003). Pellet durability tests indicated an increase from 30% in the pelleted diet to 90% in the expanded diet. Starch gelatinization increased from 10% in the pelleted to 35% in the extruded diet. This is supported by (Moritz et al., 2001), where crumbles with higher moisture and gelatinization level have lower gain:feed. Small difference in gelatinization level (~6%) lower than differences exhibited here, and decreased gain:feed could have been caused by increased moisture decreasing caloric density of the diet. Moritz et al. (2005) observed decreased feed intake and increased gain:feed in the 29% gelatinized pelleted corn vs. extruded corn with a gelatinization level of 92%. This supports the F:G results in this research where the 0% diets had a lower F:G than the 20% diets. Gonzalez-Alvarado et al. (2007), contradict our results, where the cooked corn had similar feed intakes, weight gains and feed efficiencies. Corn starch is highly digestible with reported values as high as 97% (Weurding et al., 2001). Gelatinized starch has a higher viscosity than unprocessed starch and with corn starch having a high digestibility any possible benefits of decrystallization of starch granules are negated by higher viscosities.

Geometric standard deviations were low for the corn grind used in this experiment, and the small distribution is indicative of roller mill ground corn. Different geometric standard deviations are found with hammer mill grinding and are the reason a roller mill was used, to limit the effect of geometric standard deviation. Effects of particle size showed here display an advantage for coarser grinds over finer grinds. Higher LWG's of the MP and LP are in agreement with Nir et al. (1994a), where higher weight gains and feed intakes were observed in the medium and coarse grinds. This research did not display a similar increase in feed efficiency. This could be because the fine grind was larger than the SP used in this research, and the medium particle was closer to the LP than the MP used in this research. Increase in LWG is supported by Amerah et al. (2007), however there was an increase in feed intake and decrease in

F:G, which were not seen in this research. Results of this research contradict Nir et al. (1995), where no difference was observed between coarse and fine grinds. Again the fine particle is larger than our SP, and the coarse particle is closer to the LP, than MP. Research conducted by (Deaton et al., 1995; Hamilton and Proudfoot, 1995; Kasim and Edwards, 2000) agrees with (Nir et al., 1995), and shows no difference between grind sizes. Results observed in Parsons et al. (2006), demonstrate no differences in the corn particle sizes within the range used in this research, however the coarse (2,242 µm) particle size had decreased feed efficiency, and increased intake. This is in agreement with (Kilburn and Edwards, 2001), where the fine particle size is closer to the MP used in this research had higher gain:feed. Some of the literature supports this research, with the larger particle size having higher gains, but some showed no difference as seen with the MP and LP diets.

Benefits of a grind size larger than the SP used in these experiments is supported by our results and the literature. The literature does not show similar trends as the results of this experiment, but the parameters of the research are different. The results of this experiment show a higher gelatinization level, and a particle size of 466 µm are not beneficial to broiler LWG, and in the case of the 20% gelatinization lower LWG, and higher F:G.

ACKNOWLEDGEMENTS

The authors would like to thank Robert Beckley, Robert Resser, and Elizabeth Beilke for their help with the set-up and ending of the experiment.

Figure 3.1 Distribution of Particles in the Small Particle Corn

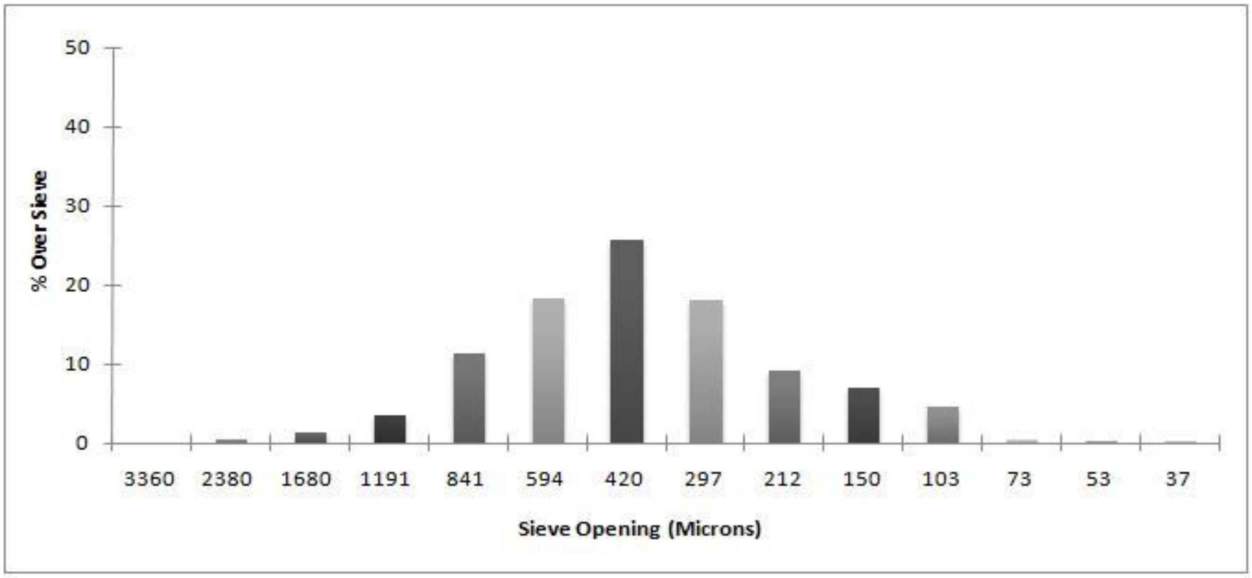


Figure 3.2 Distribution of Particles in the Medium Particle Corn

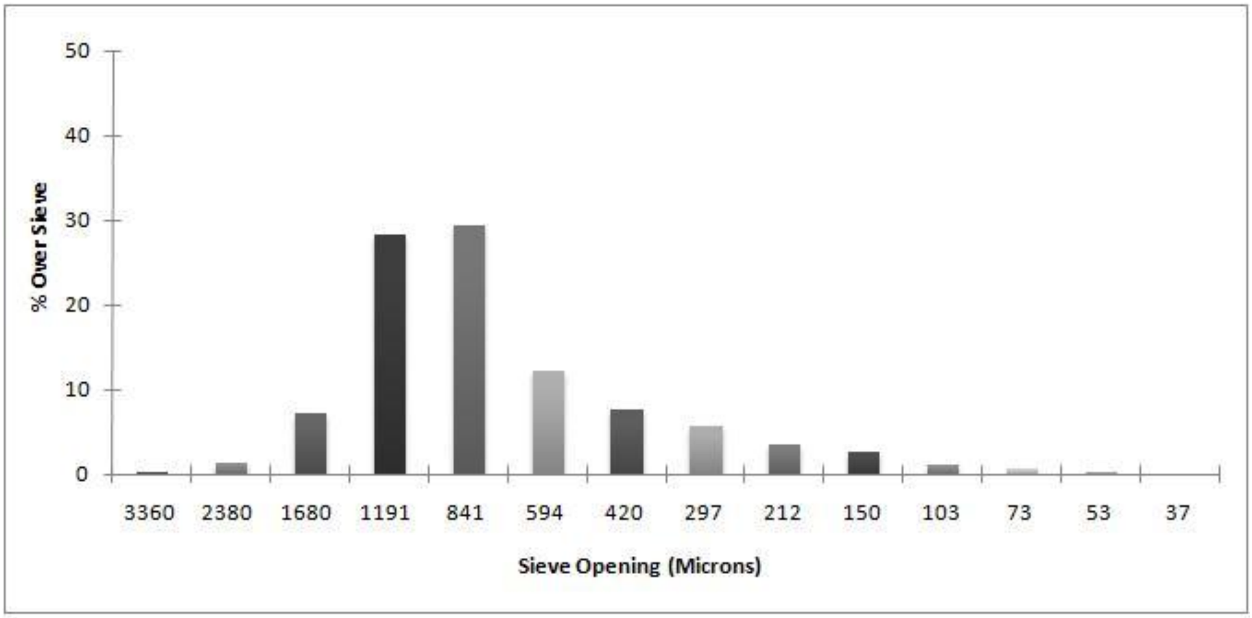


Figure 3.3 Distribution of Particles in the Large Particle Corn

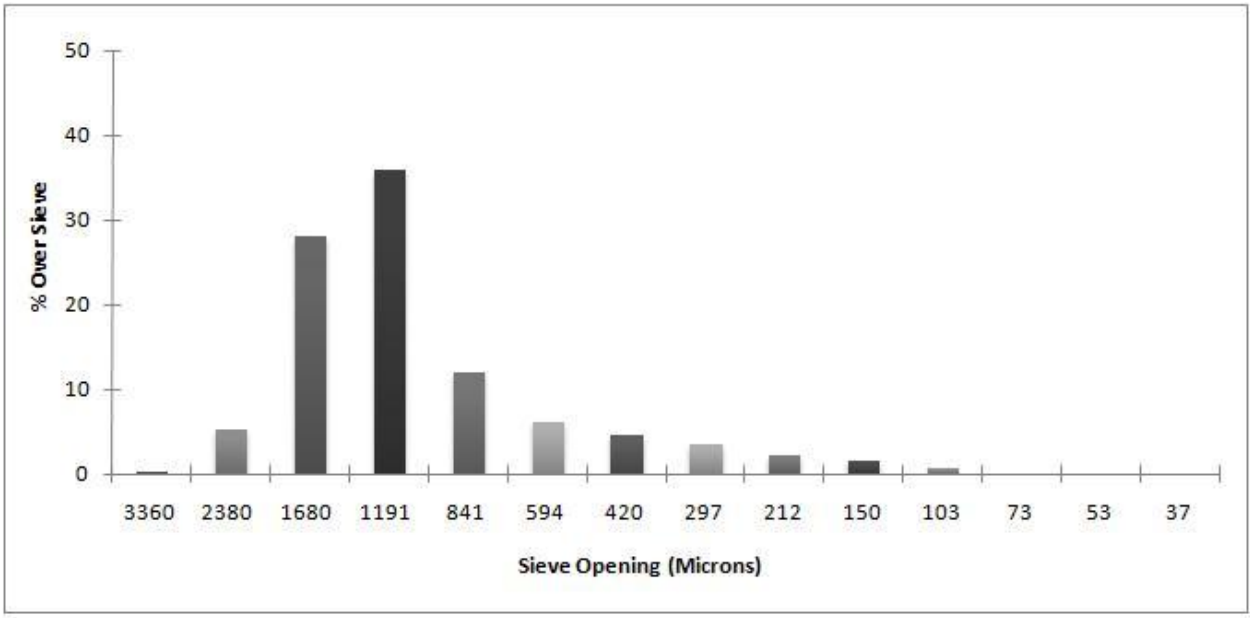


Table 3.1 Experimental Diet

Ingredients	Percent in Diet
Corn	43.24
Soybean meal (48%)	36.54
Starch/Pregelalinized starch	7.68
Soy oil	5.49
Meat and bone meal (47.9%)	4.00
Limestone	1.13
Dicalcium phosphate	0.85
Salt	0.40
$_{DL}$-Methionine	0.29
Feed additives[123]	0.36
Calculated composition	
Metabolizable energy	3200
Crude protein (%)	23
Lysine (%)	1.29
Methionine (%)	0.63
Methionine/Cystine (%)	0.98
Tryptophan (%)	0.31
Threonine (%)	0.88
Calcium (%)	1.00
Available phosphorus (%)	0.45
Sodium (%)	0.20

[1] Supplied at per kilogram of diet manganese, 0.02%; zinc, 0.02%; iron, 0.01%; copper, 0.0025%; iodine, 0.0003%; selenium, 0.00003%; folic acid, 0.69 mg, choline, 386 mg; riboflavin, 6.61 mg; biotin, 0.03 mg; vitamin B_6, 1.38 mg; niacin, 27.56 mg; panthothenic acid, 6.61 mg; thiamine, 2.31 mg; menadione, 0.83 mg; vitamin B_{12}, 0.01 mg; vitamin E, 16.53 IU, vitamin D_3, 2,331 ICU, vitamin A, 7,716 IU.

[2] Monensin 0.099 g per kg, Elanco Animal Health, Indianapolis, IN

[3] Bacitracin methylene disalicylate, 0.05 g per kg, Alpharma.

Table 3.2 Particle Size of the Corn

Corn Particle Size	GMD[1] (μm)	GSD[2]
Small Particle (SP)	465	1.89
Medium Particle (MP)	877	1.93
Large Particle (LP)	1240	1.87

[1] Geometric mean diameter
[2] Geometric standard deviation

Table 3.3 Broiler Growth Performance Data

Treatment	LWG (kg)[1]	Consumption (kg)[2]	F:G (kg feed:kg gain)[3]	Mortality (%)
% Gelatinization				
0	0.769[a]	28.010	1.232[a]	2.08
10	0.773[a]	28.298	1.244[ab]	1.67
20	0.742[b]	27.924	1.260[b]	0.69
P-value	0.018	0.623	0.022	0.112
SEM (n=24)	0.024	0.310	0.043	0.14
Particle Size				
SP	0.739[a]	27.068[a]	1.239	1.94
MP	0.779[b]	28.792[b]	1.239	0.69
LP	0.767[b]	28.372[b]	1.259	1.81
P-value	0.004	<0.001	0.837	0.131
SEM (n=24)	0.024	0.310	0.043	0.14
%Gelat x PS				
0 SP	0.739	27.066	1.234	1.67
0 MP	0.786	28.581	1.226	2.08
0 LP	0.783	28.384	1.238	2.50
10 SP	0.752	27.204	1.238	2.92
10 MP	0.796	29.442	1.237	0.00
10 LP	0.773	28.247	1.258	2.08
20 SP	0.727	26.933	1.247	1.25
20 MP	0.755	28.355	1.254	0.00
20 LP	0.745	28.485	1.280	0.83
P-value	0.855	0.726	0.837	0.382
SEM (n=8)	0.027	0.506	0.044	0.25

[a-f] Means without similar superscript within same column and treatment are significantly different ($P<0.05$)

[1] Live weight gain per bird

[2] Consumption per pen

[3] Adjusted for mortality

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