ABSTRACT

CHEWNING, CAROLINE. Evaluation of Post Pellet Liquid Application, Feed Form and Particle Size on Broiler Performance. (Under the direction of Charles R. Stark).

The objective of these studies was to determine the effect that feed manufacturing has on broiler performance. The first study evaluated the effect of the accuracy of post pellet liquid fat application (PPLA) on broiler performance. Poor application of fat has been believed to affect bird performance and production cost. The study was designed to test the effect of over and under application of poultry fat to broiler feed post pelleting. Fat was applied post pelleting to a common corn-soy diet to produce three treatment fat levels (80, 100, and 120% of target); the fourth treatment consisted of a rotation of the 80, 100, and 120% diets to match the nutrient package of the 100% treatment. BW and feed consumption were determined at 14, 35, and 45 d of age and adjusted feed conversion (AdjFCR) calculated. There were no effects on BW and FCR at 35 d of age but birds fed the diet that contained 80% fat from 35 to 45 d exhibited poorer FCR in comparison to the other treatments (1.74 versus 1.59, 1.62, and 1.63). The results indicated that under application of fat (80%) to finisher feed produced poorer FCR while over application of fat simply increased feed costs and would be expected to create shrink at the feed mill.

A second study was conducted to evaluate the effect of the accuracy of PPLA in low energy diets on broiler performance. The study was designed to test the effect of over and under application of poultry fat in the PPLA process in low energy broiler diets. Fat was applied post pelleting to a common corn-soy diet to produce three treatments (P80, P100, and
P120) with fat levels at 80, 100, and 120% of target, respectively. A fourth treatment (M100) compared the addition of 100% of the dietary fat in the mixer prior to pelleting. BW and feed consumption were determined at 14, 35, 42 and 47 d of age and adjusted feed conversion (AdjFCR) calculated. The overall AdjFCR of birds fed the P80, P100, P120, and M100 diets was 1.78, 1.77, 1.75, and 1.80. The over application of fat (P120) tended to improved AdjFCR in broilers that were fed lower energy diets.

The third study evaluated the effect of feed form and particle size on broiler performance. Previous research has shown an improvement in feed conversion with pelleted broiler diets as compared to mash diets. However, research on particle size has not clearly delineated the effect that particle size has on broiler performance. The primary advantage of a fine grind in broiler diets may be better pellet quality and fewer fines at the feeder. The experiment was a 2 x 2 factorial of feed form (pellet and mash) and particle size (300 and 600 microns). Birds were fed corn-soybean diets in either pellet (P) or mash (M) form. The average particle size in the 300 and 600 treatment diets was 267 and 570 microns, respectively. Feed consumption and BW were determined at 14, 21, 35, and 44 d of age and adjusted feed conversion (AdjFCR) calculated. The 44 d BW of the male and female birds fed the pelleted diets were higher (3,228 and 2,616 g) as compared to the BW of the mash fed birds (2,733 and 2,239 g), respectively. The overall AdjFCR of birds fed the M300 (1.94) and M600 (2.11) diets were poorer than the birds that received the pelleted diets. The results of the study confirmed that broilers perform better when fed pelleted diets.
Evaluation of Post Pellet Liquid Application, Particle Size, and Feed Form on Broiler Performance

by
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A thesis submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the degree of Master of Science.

Poultry Science

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DEDICATION

To my parents, who taught me to never give up on your dreams, no matter how impossible they may seem.
BIOGRAPHY

Caroline Gibson Chewning was born on February 15\textsuperscript{th}, 1985 and raised in Elizabeth City, NC. She graduated from Northeastern High School in 2003 and began her college career at North Carolina State University the following August. She graduated in 2007 with a Bachelor of Science degree in Biological Sciences. She began to pursue her Master of Science degree in January 2008 in the Department of Poultry Science.
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INTRODUCTION

The cost of feed is a primary concern to the poultry industry since it compromises over 60% of the total cost of production. Nutritionists, feed mill managers, and live production specialists continually look for opportunities to improve feed conversion as well as to improve growth.

The application of fat to pellets can be used to produce a better quality pellet as well as provide additional nourishment to the birds. A properly operated post pellet liquid application (PPLA) system can help reduce the shrink in feed mills as well as create a nutrient rich feed for broilers. The over application of fat reduces the feed mill’s inventory of fat and results in shrink, while the under application of fat decreases the energy available to the bird.

Research on particle reduction would help determine what particle size is the most beneficial to the broiler industry. A reduction in cereal grain particle size results in improved pellet quality and increased interaction with the digestive enzymes in the bird’s gastrointestinal tract. However, reduced particle size does not come about without an increased cost in feed mill energy consumption. The positive effect of reduced particle size on growth and feed conversion in broilers is not as clear as in swine. Research conducted in cages and pens have reported conflicting results concerning the effect of reduced particle size on performance. A negative effect of reduced particle size is decreased gizzard development. A finely ground grain will reduce the amount of work required by the muscles in the gizzard to break down the grain as compared to a coarser grain. Ultimately this results in smaller
gizzards and decreased gut function, which translates into a loss in sales and poorer feed conversion.

The modern broiler industry has traditionally fed a pelleted diet to birds due to improved BW gain and feed conversion as compared to birds fed mash diets. Heavy birds fed pelleted diets have increased feed consumption, especially during the last 10-14 day of growth.
CHAPTER ONE

LITERATURE REVIEW
Post Pellet Liquid Application

Poultry companies continuously seek methods to reduce costs but still provide adequate nutrition. The PPLA system was developed to minimize the amount of fat in the mixer in order to improve pellet quality as well as apply enzymes, micro-ingredients, and fat to pelleted feed [1]. Research has shown that removing the fat from the meal before pelleting improves pellet quality [1]. The goal of the PPLA equipment is to uniformly distribute the liquid to the outside of the pellet.

Advancements in PPLA system technology have allowed feed manufacturers to produce feed that more closely meets the dietary requirements set forth by nutritionists [2,3]. In addition to improved accuracy, PPLA systems found in the industry today have been reported to require minimal maintenance [2].

Several types of PPLA systems exist in the industry; systems have been typically categorized by the method in which they measure dry feed and liquid addition. Volumetric systems direct a constant volume of dry feed into the liquid application chamber [1,2]. Mass flow systems continuously measure the pressure of feed as it flows across an impact plate [1,2]. Gravimetric feeders use a load cell to continuously monitor the weight as it flows through a drag or screw conveyor [1]. The industry initially installed volumetric and mass flow feeders due to their lower installation cost as compared to gravimetric feeders. Although gravimetric feeders have the highest cost, they are the most accurate available [1].

PPLA systems use mechanical or coriolis meters to measure liquid addition. Once the liquid has been measured, a coater is used to apply the liquid to the dry feed. Common
systems are spinning disk, spray chamber, and batch systems for combining dry feed and liquids. The RotoCoater system sprays liquid onto high speed rotating disks. The high speed disks then distribute the fat in a mist form onto the pellets [4]. Another common applicator is the spray chamber where a nozzle is used to spray the liquid onto the pellets as they move through the chamber. Batch mixing has been commonly used in Europe where a paddle mixer is used to coat and mix the liquid and pellets.

After coating, pellets enter a mixer or screw conveyor that further aids in the distribution of the liquid. Mixing of the feed has helped provide a more uniform coating of the pellets [4]. However, the additional mixing time has increased the percentage of fines to pellet ratio, and therefore must be closely monitored.

The common denominator in these systems is that they measure dry feed and liquids separately, and then combine them based on a pre-determined proportion. The primary difference in these systems is how the dry feed and liquid are measured and combined.

Ongoing research has focused on improvement of the accuracy of the PPLA system. A CV of 15% has become generally accepted as a reasonable accuracy for a PPLA system [2]. If the feed mill accurately applied the amount of fat required, it could save thousands of dollars a year.

Energy

Although PPLA systems have improved, nutritionists remain concerned about the effect of under and over application of a liquid ingredient and the effect on animal performance. An under or over application of fat could change the energy content of the
broiler diet. Research has shown that high energy diets fed to broilers maximized growth and performance [5]. Fat supplementation has been widely used to create high energy diets [6]. Leeson et al. [5] determined that supplemental fat changed the energy content of the feed. Researchers have shown that fat supplementation increased the use of metabolizable energy calories in a manner that they termed as “extra caloric” effect [6,7,8,9]. The high energy diets resulted in an increased weight gain and improved feed efficiency [10,11,12]. In addition to the extra energy, the supplemental fat may also improve the digestibility of the feed [6]. Brue et al. [6] reported birds that consumed a higher ME caloric diet had a lower FCR. Researchers have also demonstrated that birds fed additional energy required fewer days to reach the target BW and had improved FCR [6,13,14]. Although fat supplementation has been shown to benefit broilers, Leeson et al. [14] suggested that broilers can adapt to low energy diets. Previous studies have shown birds fed lower energy diets were more efficient in converting energy to BW gain but their feed intake increased to compensate for the reduced caloric intake [14,15]. However, as the broiler industry transitions to heavy bird weights the bird’s ability to consume enough feed and energy may restrict growth, especially during the last 7 to 10 days.

Feed Form

Researchers and nutritionists continually explore options to reduce broiler production costs. Pelleted feed has been shown to have the greatest potential to improve feed conversion and reduce cost [16,17]. These improvements have been associated with changes in nutrients, digestibility, and less feed wastage [18]. The pelleted form of feed has previously
been shown to increase BW and improve feed conversion in both broilers and turkeys [19,20]. A study conducted by McKinney et al. [19] evaluated the effect of feeding pellets versus mash diets and the effect of pellet quality that ranged from 100% to 20% pellets in comparison to a mash feed, with birds showing a preference for the pellets without fines, respectively. The BW gain and FCR reported for the 100% pellet diet was 725 g and 1.87, however as the diets decreased in the percentage pellets and increased in percentage fines, there was a reduction in BW gain and birds had a poorer FCR. The mash diet resulted in a BW gain of 643 g and a FCR of 2.02. Similar results were found by Nir et al. [20], the pelleted feed form improved BW and FCR over the mash feed.

Pelleted feed decreases feed ingredient separation, feed wastage and improved palatability [21]. Behnke et al. [21] stated that the bird’s anatomy may cause feed wastage since without teeth it is more difficult to grasp the feed from feeder. Birds consuming mash diets that contained inconsistent particle sizes easily dropped feed particles. In addition to feed wastage, it has been proposed that birds consuming mash diets expended extra energy to consume enough feed to meet their energy requirement for growth due to spending more time at the feeder. Research has demonstrated that birds fed mash feed and pelleted diets that contain a large amount of fines, required extra standing and eating time, therefore the birds were expending extra energy for these activities. The poorer FCR of birds fed mash diets supported the theory that extra energy is required to stand and eat at the feeders [21].

Although the benefit of pelleted diets has been documented the effect of pellet quality is not as well documented in the literature. The current research has suggested that the
beneficial effect of pellets was reduced when birds received poor quality pellets. Briggs et al. [22] reported a poor quality pellet resulted in a high number of fines that were poorly consumed. Lemme et al. [23] conducted a study that tested the broiler response to poor quality and good quality pellets. During the study, birds fed the good quality pellets had the highest BW gain and feed intake. McKinney et al. [19] reported feed conversion improved by 5% when birds were fed pelleted diets in comparison with mash diets.

Particle Size

One option to improve pellet quality is through reduced ingredient particle size. Stark [24] reported that decreasing the particle size of corn and soybean meal resulted in improved pellet quality. Particle size reduction also facilitated greater interaction with digestive enzymes because of the greater amount of surface area available for enzyme access in the animal [16,25]. Research conducted in swine has shown a linear improvement in the FCR of finishing pigs as the particle size of the cereal grain in the diet decreased [25]. The success of particle size reduction in the swine industry has led to research in the poultry industry to determine if a similar effect existed in broilers.

Poultry research results concerning reduced particle size vary widely. The interaction between the feed form and particle size has been reported, but particle size responded differently when fed in mash diets. Amerah et al. [18,19] conducted several studies that indicated a coarse grind feed in mash form resulted in the lowest feed to gain ratio. In addition to particle size reduction research these studies compared the effect of particle size
reduction of wheat and corn in broiler diets. The research suggested that wheat should be more coarsely ground than corn possibly due to difference in endosperm hardness [17,20].

Results of a smaller particle size effect on gizzard development have been controversial. Nir et al. [20] and Engberg et al. [25] demonstrated a benefit to smaller particle size on the development of the gizzard. Other research has shown reduced gizzard development when birds received finely ground corn. A well-developed gizzard has been reported to improve feed utilization and lowered production costs [26]. Although particle size may be manipulated to improve broiler performance and reduce cost, the form of feed must be factored in. Large particle size has been shown to have a positive effect on broiler performance when fed in mash form [20]. Coarse particle size ingredients required a longer time inside the gizzard [17]. Coarser particle size required an increase in the time that feed remained in the gizzard, which increased gizzard activity and improved function [17]. Santos et al. [27] discovered that coarser diets resulted in heavier gizzard weights due to the increased amount of work needed to digest the particles.

In addition to the negative effect of reduced gizzard weights and gut health, the additional cost of grinding the grain must be taken into account. Since cereal grains make up 60-70% of the diet and feed costs represent up to 70% of the total cost of production any benefits associated with improved FCR would have to be large enough to offset the higher cost of grinding [16].
REFERENCES


CHAPTER TWO

EFFECT OF ACCURACY OF POST-PELLET LIQUID APPLICATION OF FAT ON BROILER PERFORMANCE
SUMMARY

An experiment was conducted to evaluate the effects of the accuracy of post-pellet liquid fat application (PPLA) on broiler performance. Fat content of feed has been routinely used to monitor feed quality and explain shrink at feed mills. Furthermore, poor application of fat has been believed to affect bird performance and production costs. These studies were designed to test the effect of over and under application of poultry fat to broiler feed post pelleting on broiler performance. The first study used 1,024 male broiler chicks that were randomly assigned to one of four treatment diet series with 8 replicate pens per treatment and 32 birds per pen. Fat was applied post-pelleting to a common corn-soy diet to produce three treatment fat levels (80, 100, and 120% of target), while birds on the fourth treatment (blended) were randomly fed the 80, 100, and 120% fat diets to match the nutrient package fed to birds assigned to the 100% treatment. Diets were formulated to contain a total of 7.7, 7.4, and 6.3% fat in the starter, grower, and finisher feeds, respectively. BW and feed consumption were determined at 14, 35, and 45 d of age and adjusted feed conversion ratio (AdjFCR) calculated by including the weights of all dead birds. Feed was analyzed for crude fat and the percentage total fat fed to the birds was calculated for each diet. Results showed that the birds received 84, 103, and 124% of target in the starter feed, 85, 101, and 121% of target in the grower feed, and 78, 98, and 115% of target in the finisher feed for the respective 80, 100, and 120% treatments. There were no effects on BW and AdjFCR.

A follow-up experiment was conducted to evaluate the effect of the accuracy of PPLA in low energy diets on broiler performance. The experiment was designed to test the
effect of over and under application of poultry fat in the PPLA process in low energy broiler diets. A total of 1,024 male broiler chicks were randomly assigned to one of four treatment diet series with 8 replicate pens per treatment and 32 birds per pen. Fat was applied post-pelleting to a single common corn-soy diet to produce three treatments with fat levels at 80, 100, and 120% of target, respectively. A fourth treatment, mixer, compared the addition of 100% of the dietary fat in the mixer prior to pelleting. Diets were formulated to contain a total of 6.8, 7.0, and 6.9% fat in the starter, grower, and finisher feeds, respectively. BW and feed consumption were determined at 14, 35, 42 and 47 d of age and adjusted feed conversion ratio (AdjFCR) calculated. Feed was analyzed for crude fat and the percentage total fat fed to the birds was calculated for each diet. Results showed that the birds received 74, 106, 116, and 84% of target in the starter feed, 77, 101, 119, and 87% of target in the grower feed, and 86, 101, 119, and 107% of target in the finisher feed for the respective 80, 100, 120, and mixer treatments. There were no effects on BW at 47 d of age. The AdjFCR of birds fed the 80, 100, 120, and mixer treatments were 1.86, 1.85, 1.80, and 1.87, respectively. The over application of fat (120) improved AdjFCR in broilers that were fed lower energy diets.

**DESCRIPTION OF PROBLEM**

PPLA systems have been used to apply enzymes, micro-ingredients, and fat to pelleted feed [1]. Ongoing improvements in PPLA systems have allowed feed manufacturers to produce feed that more closely met the dietary requirements set forth by nutritionists [2,3]. A CV of 15% has been generally accepted as reasonable accuracy for a PPLA system [1]. Although
PPLA systems have improved, nutritionists remain concerned about the effect of over and under application of a liquid ingredient and the effect it has on animal performance. An over or under application of fat will change the energy content of the broiler diet. Research studies have shown birds adapt to lower energy diets by increasing their feed intake [4]. Although birds can adapt to diet energy modifications, researchers have demonstrated that birds fed additional energy required fewer days to reach their target BW and had improved FCR [5,6]. The hypothesis has been that the addition of fat provided extra calories, which when fed in proportion to amino acids resulted in improved bird performance. The objective of these studies was to determine the effect on broiler performance of varying the energy content of the diet due to the under and over application of fat.

METHODS AND MATERIALS

Feed Formulation and Manufacturing

Feed was produced at the North Carolina State University Feed Mill Educational Unit. Diets were formulated to meet or exceed NRC [7] requirements (Tables 1 and 2). The diets in Experiment 1 were formulated to a ME content of 3,150, 3,200, and 3,200 kcal/kg in the starter, grower, and finisher diets, respectively. A common corn-soy basal diet was manufactured for each of the starter, grower, and finisher diets. The meal was conditioned to 85°C for 20 s and pelleted using a 4.4 mm x 32 mm die [8]. Feeder rate was held constant to ensure similar conditioning and pellet quality parameters during the pelleting process. The starter diet was fed as crumbles and the grower and finisher diets were fed as pellets. Post-pellet fat was applied to the cooled crumbles or pellets in a double ribbon mixer. Fat was
added to the crumbles and pellets to achieve feeds that contained 80, 100, and 120% of the target formula value of fat (6.98%) in Experiment 1. The diets in Experiment 2 were formulated to a ME content of 3,035, 3,100, and 3,150 kcal/kg in the starter, grower, and finisher diets, respectively. The manufacturing process described in Experiment 1 was used to produce the 80, 100, and 120 % of target fat (4.87%) treatment diets in Experiment 2. The fourth treatment diet (mixer), in Experiment 2, was produced by adding fat to the original feed batch in the double-ribbon mixer prior to pelleting.

**Bird Management**

The two experiments were conducted at North Carolina State University Chicken Educational Unit. The care of the birds used in the trial conformed to the Guide for Care and Use of Agriculture Animals in Agriculture Research and Teaching [6]. A total of 1,024 male birds (Ross 344 x 708SF) [9] were weighed and placed on the day of hatching in a curtain-sided house on new litter. Thirty-two birds were placed in each pen and a total of 32 pens were used. Each pen was 1.2 m wide by 3.8 m long. There were four treatments in Experiments 1 and 2, with eight replicates of each treatment. Birds had ad libitum access to feed and water. The lighting program started with 23 h of light for the first seven days, 22 h until 14 d and 20 h until 21 d, natural light was used thereafter. The temperature from hatching to 7 d was kept at 34 to 32º C, 29º C to 14 d, 27º C to 21 d, and ambient thereafter.

**Experiment 1**

The birds in Experiment 1 were fed 0.7 kg of starter feed to 14 d, 2.7 kg of grower from 15 to 35 d, and 2.7 kg from 36 to 45 d. Birds were assigned to one of four treatments (80, 100,
120, or blended). The birds assigned to the blended treatment were fed on a predetermined schedule in which the 80, 100, and 120 treatment feeds were rotated each time feed was added to the feeders in the other treatments. Birds fed the blended diets were thus sequentially fed 0.23 kg/bird of the 120, 80, and 100 starter diets, 0.45 kg /bird of the 80, 100, 120, 80, 120, and 100 grower diets, and 0.45 kg/bird of the 80, 120, 100, 100, 80, and 120 finisher diets. The birds fed the blended treatment were fed a complete nutrient package within each production phase to match the 100 treatment. Feeders were shaken once per day to 14 d, twice per day to 35 d, and three times per day until 45 d to prevent bridging in the feeders.

**Experiment 2**

The treatments in Experiment 2 consisted of 80, 100, 120, and mixer. The fat in treatments 80, 100, and 120 was applied post-pelleting. The fat for the mixer treatment was applied in the mixer prior to pelleting. Birds were fed 0.9 kg of starter feed to 14 d, 3.2 kg of grower from 15 to 35 d, and 3.6 kg of finisher from 36 to 47 d. Feeders were shaken once per day to 14 d, twice per day up to 35 d, and three times per day until 47 d to prevent bridging in the feeders.

**Data Collection**

Initial pen BW was recorded in Experiments 1 and 2 at 1 d of age. The birds in Experiment 1 were counted and BW recorded at 14, 35, and 45 d of age. The birds in Experiment 2 were counted and weighed at 14, 35, 42, and 47 d of age. Feed consumption was calculated in
conjunction with each BW. Dead birds were removed and weighed daily. Feed conversion (AdjFCR) was adjusted for mortality by adding mortality weight to pen weight.

**Analytical Methods**

The crude protein [10], crude fat [11], and moisture content [12] was determined for each diet, before fat application and after. The pellet quality as defined by the pellet durability index [13] was determined on finished pelleted feed.

**Data Analysis**

Both experiments were a randomized block design. Data were analyzed with the proc GLM procedure of SAS [14]. The least squares procedure was used to separate treatment means with significance set at $P < 0.05$. The model for Experiment 1 and 2 included block and dietary treatment.

**RESULTS AND DISCUSSION**

**Experiment 1**

The total crude fat analysis of the diets were within ± 5% of the target fat content (Table 3). Laboratory analysis of crude fat in the feed indicated the 80 diet contained 84, 85, and 78% of target, the 100 diet contained 103, 101, and 98%, and the 120 diet contained 124, 121, and 115% of target in the starter, grower, and finisher diets, respectively. Although the samples were within ± 5% of the target there was still variation due to manufacturing, sampling, and laboratory analysis. Pellet quality for the grower phase as determined by the PDI standard method [13] was 87 and 59% when modifiers (three 19.05 mm hex nuts) were added to the procedure. The results of the experiment indicated that the over or under application did not
significantly affect BW, feed intake and AdjFCR (Table 4) when birds were fed high energy diets. Birds fed excess energy due to over application of fat were slightly heavier throughout the study but this did not translate into a heavier bird at 45 d of age. Researchers have observed that varying levels of energy did not change BW in heavy birds grown to 49 d; however, decreased energy levels in the diets resulted in poorer AdjFCR [4,15,16]. The birds fed the 100 diet had a 1.77 AdjFCR, while birds fed the 80 and 120 diets had identical AdjFCR (1.82), which suggested that diets formulated to 3200 kcal/kg were above the energy requirement of the birds during the growing and finishing phases. Leeson et al. [15] demonstrated that birds fed lower energy diets (2,700 kcal/kg) increased their feed intake in order to consume more calories to meet their energy needs. The birds in this study did not increase their feed intake when they received the feed that contained 80% of the target fat in the diet, which suggested that they had met their daily caloric requirement. The blended treatment in which the birds were fed varying levels of fat at each feeding was not different from the 100 treatment (Table 4). Broilers in this study were able to compensate and adjust to varying levels of fat between feedings, which also has been observed in other experiments [4,15]. These results indicated that bird performance was not compromised due to variation in the amount of fat in the diet when fed over a short period of time. The results of this experiment indicated that birds fed a high energy diet that contained 80% of the target fat did not have poorer performance and that the varying amount of added fat between feedings did not affect broiler performance.
Experiment 2

Dietary crude fat analysis showed that the diets were ± 6% of the target fat in the PPLA treatments (Table 3). Laboratory analysis of crude fat in the feed indicated the 80 diet contained 74, 77, and 86% of target, the 100 contained 106, 101, and 101% of target, and the 120 diet contained 116, 119, and 119% of target for the starter, grower, and finisher feeds, respectively. The crude fat analysis results of the mixer treatment were low for the starter (5.8%) and grower (6.1%) feeds as compared to the finisher feed (7.4%), which equaled 84, 87, and 107% of target, respectively. More variation was observed in the mixer treatment as compared to the PPLA treatments. The PDI of the feed prior to PPLA was 86% pellets. The addition of the fat to the mixer lowered the PDI of the pellets to 56%, which was in agreement with the findings of Dozier et al. [16] and Stark [17]. There was no difference in BW of the birds in Experiment 2 (Table 5), similar to the findings of Experiment 1. However, the AdjFCR of the birds fed the 120 diet was improved as compared to the 80 and 100 treatments at 47 d at age. The AdjFCR response of broilers fed low energy diets was consistent with those of Leeson et al. [4,15] and Dozier et al. [16] in which lower energy diets resulted in poorer AdjFCR. The birds fed the 120 diet were able to utilize the extra fat, which was over applied to the feed during manufacturing. Treatments 100 and mixer resulted in similar performance. Treatment 100 BW was 3,300 g compared to the mixer treatment of 3,255 g at 47 d of age. Overall AdjFCR, of the Treatment 100 was 1.85 compared to the mixer treatment of 1.87, was not significantly different. Overall, the 120 treatment had the best AdjFCR during the growing and finishing phases of growth. The over
application of fat, which resulted in additional calories, improved AdjFCR. The results of Experiment 1 and 2 indicated that birds can adjust their feed intake to account for the over or under application of fat in a PPLA system as well as variation between loads of feed delivered to the flock. The under application of fat in both experiments resulted in an inventory gain in the feed mill, and did not appear to have a negative effect on broiler growth rate. Experiment 2 does point out that over application of fat can improve AdjFCR in marginal energy diets. However, the over application of fat to diets that were formulated to meet the caloric intake of the birds did not improve BW or AdjFCR and resulted in a shrink in fat inventory at the feed mill, without a performance benefit in the field. Thus, the additional fat is an economic loss in an integrated production system.

CONCLUSIONS AND APPLICATIONS

1. Birds fed the low energy diets responded to the highest application of fat on pelleted diets.
2. Broiler performance was not affected by variation in fat addition levels within a short feeding period.
3. The final BW of broilers was not affected by the energy content of the diet.
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10. AOAC. 1995. Protein (Crude) in Animal Feed, Combustion, AOAC Official Method 990.03 A-D.


CHAPTER THREE

EFFECT OF PARTICLE SIZE AND FEED FORM ON BROILER PERFORMANCE
SUMMARY

A study was conducted to evaluate the effect of feed form and particle size on broiler performance. Previous research has shown an improvement in feed conversion with pelleted broiler diets as compared to mash diets. However, research on particle size is not as clear concerning the effect that particle size has on broiler performance. One advantage to a fine grind is better pellet quality and fewer fines at the feeder. The experiment was a 2 x 2 factorial of feed form (pellet and mash) and particle size (300 and 600 microns). A total of 1,024 broiler chicks, 512 males and 512 females, were randomly assigned to one of the four treatments with eight replicate pens per treatment. There were 32 birds per pen, 16 males and 16 females, and a total of 32 pens. Birds were fed corn-soy meal diets in either pellet (P) or mash (M) form. The starter P diet was crumbled; the grower and finisher P diets were fed as pellets. The corn was ground with a hammermill equipped with either a 1.6 mm or 7.9 mm screen to produce the two particle sizes. The average particle size in the 300 and 600 treatment diets was 267 and 570 microns, respectively. Pellet quality as measured by pellet durability index of the P300 diets and P600 diets, was 88 and 84%, respectively. The 44 d BW of the male and female broilers fed the pelleted diets were higher (3,228 and 2,616 g) as compared to the BW of the male and female broilers fed mash diets (2,714 and 2,240 g), respectively. The birds fed the smaller particle size had a significantly higher BW to 21 d. After 21 d, the BW difference between the diets diminished but the 300 diet continued to have slightly higher BW. The overall AdjFCR of birds fed the M300 (1.94) and M600 (2.12) diets were poorer than the birds that received the pelleted diets. There was no significant
difference in AdjFCR of birds fed the P300 (1.88) and P600 (1.85) diets. The results of the study showed that broilers performed better when fed pelleted diets and demonstrated positive BW response to feeding finer particles up to 21 d.

**DESCRIPTION OF PROBLEM**

Researchers and nutritionists continually explore options to reduce broiler production costs. Particle size reduction and pelleting have been shown to improve feed conversion and reduce feed cost in both swine and poultry [1,2]. Research has demonstrated that the broilers fed pelleted feed compared to meal feed have higher BW and improved feed conversion [3,4]. Pelleted feed also has the benefits of decreased feed ingredient separation, decreased feed wastage, and improved the palatability [5]. These benefits tend to decrease when birds are fed low quality pellets or a high percentage of fines [3]. Briggs et al. [6] reported that a poor quality pellet resulted in a high percentage of fines that were not consumed by birds. One option to improve pellet quality is the reduction of particle size of the cereal grain. Particle size reduction also allows for greater interaction with digestive enzymes due to the increased amount of surface area on the grain particle [1,7]. However a potential negative effect of reduced particle size is poor gizzard development, which is important for feed utilization and intestinal health [8]. Results of the effect that particle size has on gizzard development have been inconclusive. Nir et al. [9] stated the coarseness of feed increased the relative gizzard weight. However, there has been speculation over what caused the larger gizzard weight; Amerah et al. [2] suggested gizzard stimulation was due to the length of time that the coarse particles reside in the gizzard. In addition to particle size reduction as a method to improve
broiler performance and reduce cost, the effect of feed form must be considered in combination with particle size. The purpose of this study was to determine if particle size, feed form, and the interaction between particle size and feed form has an effect on broiler performance.

MATERIALS AND METHODS

Broiler Management

Experiment 3 was conducted at the North Carolina State University Chicken Educational Unit. The care of the birds used in the trial conformed to the Guide for Care and Use of Agricultural Animals in Agriculture Research and Teaching [10]. A total of 512 male and 512 female 1 d old chicks (Ross 344 x 708 SF) [11] were weighed and placed on the day of hatching in a curtain-sided, environmentally monitored broiler house for 44 d. Thirty-two birds were placed per pen, with 32 pens total. Each pen was 1.2 m wide by 3.8 m long. There were eight replicates per treatment, with four treatments total. Birds had ad libitum access to water and feed throughout the study. Feeders were shaken once per day until 14 d, three times per day until 35 d, and four times per day from 35 d until termination of the experiment. The lighting program provided 23 hours of light from 1 to 7 d, 22 hours of light to 14 d, 20 of light to 21 d and natural light afterwards. The temperature from hatching to 7 d was kept at 34 to 32º C, 29º C to 14 d, 27º C to 21 d, and ambient thereafter.

Feed Formulation

A corn-soy meal basal diet was manufactured for starter, grower, and finisher feeds. The basal starter diet was formulated to contain 23% CP, 1.26% Lys, and 0.96% Met + Cys. The
grower basal diet contained 20% CP, 1.10% Lys, and 0.83% Met + Cys. The finisher basal diet contained 18.5% CP, 1.10% Lys, and 0.75% Met + Cys. Each diet was iso-nutritive, and all diets met or exceeded the NRC requirements [12]. Corn was ground with a hammermill [13] equipped with 1.6 mm screen to achieve 300 microns average particle size and 7.9 mm screen to achieve an average particle size of 600 microns for starter, grower, and finisher basal diets. The pelleted diets were pelleted at 82°C using a 4.4 mm by 32 mm die [14]. Feed forms, crumble/pellet or mash, were created from each basal depending on the treatment. The birds were fed 0.7 kg/bird of starter, 2.7 kg/bird of grower, and 2.7 kg/bird of finisher diet.

**Data Collection**

Initial pen body weights were collected at 1 d of age. Body weights and feed consumption were determined at 14, 21, 35, and 44 d of age. Dead birds were removed and weighed daily to calculate mortality. Feed conversion (AdjFCR) was adjusted for mortality by adding the mortality weight to the pen.

**Analytical Methods**

Ground corn samples were analyzed for particle size [15] with the addition of sieve agitators and 0.5 g of a dispersing agent [16]. Feed samples were analyzed for CP [17], moisture [18], and gross energy [19]. The percentage fines in the diet were determined by sieving a sample of the pelleted feed collected and cooled through a No.5 sieve. The percentage fines were then calculated by dividing the amount of fines by the total amount of each sample. Pellet
quality as measured by the Pellet Durability Index (PDI) [20] was determined on samples collected at the pellet mill die.

**Data Analysis**

The experiment was a 2 x 2 factorial, randomized block design: feed form (pellet vs. mash) and particle size (300 vs. 600). Data were analyzed with the proc GLM of SAS. Means were partitioned by least squares means and significant set at \( P < 0.05 \). The model for Experiment 3 was block, particle size, feed form, and sex.

**RESULTS AND DISCUSSION**

Particle size of the ground corn in the P300 treatment was 269, 263, and 269 microns and the P600 treatment was 615, 536, and 519 microns for the starter, grower, and finisher diets, respectively. Pellet quality, as determined by the PDI, for P300 was 89, 85, and 87% compared to the P600 at 86, 82, and 84% for the starter, grower, and finisher diets, respectively (Table 10). These data were consistent with previous research, the smaller particle size created a more durable pellet [21]. The diet that contained finely ground corn (P300) contained fewer fines, 15, 22, and 6 % compared to the P600 at 17, 27, and 8% for starter, grower, and finisher diets, respectively.

The results of Experiment 3 indicated that both feed form and particle size affect BW of both male and female broilers at 44 d of age. Broilers fed pelleted diets had consistently higher BW throughout the study. The overall BW of male and female broilers fed pelleted diets was 3,227 and 2,615 g compared to the mash fed broilers 2,714 and 2,239 g. A study conducted by Nir et al. [4] reported similar effects due to feed form. The male broilers fed
pellets exhibited a significantly higher BW of 2,298 g compared to the mash diet, 2,236 g [4]. Female broilers had a positive response to pelleted feed at 35 d and 42 d, but the overall BW of pelleted feed was 1,923 g compared to the mash, 1,903 g [4]. McKinney and Teeter [3] also concluded that pellets resulted in higher BW gain, 725 g, versus a gain on mash of 643 g, during a 7 d period. A cage study, performed by Lemme et al. [22], evaluated the difference between coarse mash, poor quality pellets, and good quality pellets on broiler performance. Their study results indicated that good quality pellets had the highest overall BW gain [22].

The BW results observed in the current study were similar to results reported by others. Results of particle size reduction showed an improvement in BW up to 21 d, but the overall effect of particle size on BW at 44 d was not different. The lack of difference in BW observed in our study was similar to the results reported by Amerah et al. [2] who reported no significant difference in BW gain due to fine and coarse particle sizes.

The AdjFCR results due to feed form observed in the study were similar to the effects of BW. The pelleted diets outperformed the mash diets. Pelleted diets had an AdjFCR of 1.87 compared to 2.03 for the mash diets. Amerah et al. [23] reported a similar trend in which birds fed pelleted diets had an AdjFCR of 1.52 while the birds fed mash was 1.67 at 21 d. McKinney et al. [3] compared the amount of pellets versus fines in the broiler diet for 7 d and as the percentage of fines increased, the FCR increased. Results from that study showed pellets had the best FCR, 1.87, compared to mash diets, 2.02 [3].
Particle size had an affect on the AdjFCR. The present study demonstrated an improvement in AdjFCR when birds were fed mash diets that contained ground corn with a particle size of 300 microns versus 600 microns. In contrast to these results others have reported improved AdjFCR of 1.58 versus 1.62 when birds were fed a coarse versus medium particle size, respectively [23]. A follow-up study by Amerah et al. [2] resulted in an AdjFCR of 1.41 and 1.49 in birds fed coarse and fine particle grain, respectively. The difference in results could be due to the large particle size that was used in the studies. Amerah et al. [23] reported particle size of 839 and 1,164 microns while the previous Amerah et al. [2] study compared particle sizes of 297 and 528 microns. In contrast to the Amerah research, our study compared male and female broilers, while the Amerah studies [2,23] used only male broilers.

The combination of corn ground to 300 or 600 microns and fed as a pellet produced a lower AdjFCR throughout the study. Birds fed the M300 diet had a better AdjFCR overall as compared to M600. The smaller particle size of the corn in the pelleted diet produced a better quality pellet and less fines (Table 10). Conversely, pellets made with coarse grain particles have been found to deteriorate as the pellet moved through the manufacturing process and feed delivery system to the feeder.

The performance of the broilers fed the pelleted diets was not changed due to the particle size of the grain. The 44 d BW and AdjFCR of the males and females fed the P300 and P600 diets were the same. Although there was no significance difference in AdjFCR based on the particle sizes that were evaluated, the birds fed the coarser grain in the pelleted
diets had better AdjFCR, which is in agreement with other researchers [2,23]. Pellets that contain coarser material dissolved slower in the crop, which increased time needed to digest, therefore improving feed utilization [4].

In the present study, birds fed the mash diets had slightly larger gizzard weights and gizzard weights relative to BW (g/100g) as compared to the birds that received the pelleted feed (Table 11). The coarser grain particle size resulted in the highest gizzard weights, 38.1 and 33.6 g, in both the mash and pellet feed forms, respectively. A study conducted by Parsons et al. [24] observed a positive broiler growth response with increased mash particle size and birds fed the coarse diet had the largest gizzard weight. The birds fed the coarse corn mash reported a gizzard weight of 41 g, which was significantly larger than the gizzard weight of the birds fed the fine corn mash treatment (35 g) [24]. The gizzard weight as a percentage of live weight (% LW) results were similar; birds fed the coarse grain had a 1.81 % LW compared to 1.51 % LW in birds that received the fine mash [24]. Data from the present study followed the same trend. Research supports this finding as the coarser grain forces the bird to work harder to grind the particles [25]. The results of this study indicated birds that consumed the coarse grain exerted more energy to break down and digest the grain.
CONCLUSIONS AND APPLICATIONS

1. The pelleted feed form resulted in a higher BW and improved AdjFCR compared to the mash feed form.

2. The finer ground grain resulted in poorer AdjFCR compared to the coarser grain.

3. The interaction between feed form and particle size was not present in the pelleted treatments; the digestibility of the pelleted feed was the same at both particle sizes.

4. Broilers fed mash feed that contained the finer ground grain had slightly higher BW and better overall AdjFCR.
REFERENCES


11. Aviagen Inc, Huntsville, AL.

13. Master Model HD, California Pellet Mill Co.. Crawfordsville, IN.

14. Model 1522 Roskamp Chamption, California Pellet Mill Co.. Crawfordsville, IN.


16. Silicon Dioxide, model SSA-58, Gilson, Lewis Center, OH.

17. AOAC. 1995. Protein (Crude) in Animal Feed, Combustion, AOAC Official Method 990.03 A-D.


SUMMARY AND CONCLUSIONS

Results from our experiments have shown that feed manufacturing affected broiler performance. Previous research has shown that body weight (BW) and adjusted feed conversion (AdjFCR) improved due to manipulation of feed by the addition of supplemental fat or modifications to the feed form and particle size.

Fat supplementation has been used as a low cost alternative to generate high energy diets. Research studies on post pellet liquid application (PPLA) suggested the birds were able to adapt to lower energy diets by increased feed intake. In the present studies, BW and feed intake were not affected by fat supplementation in Experiment 1 or 2. However, Experiment 2, which used low energy diets, reported an improved AdjFCR of 1.80 overall when birds were fed the diets with over application of fat (120). These birds were consuming a diet that contained 400 kcal/kg less then birds in Experiment 1 overall. The lack of bird response to the supplemental fat in Experiment 1 suggests the broilers can adjust to their feed intake depending on the caloric value of the feed.

Research on broiler response to pellet and mash feed forms has resulted in conflicting reports. Although broilers have been commonly fed the pelleted feed form, there has been speculation on whether particle size manipulation has beneficial effects when fed in the mash or pelleted form. In Experiment 3 the effect of feed form and particle size as well as the interaction on broiler performance was examined. As previous research indicated, the pelleted feed form resulted in a significantly higher BW and feed intake and an improved AdjFCR compared to mash overall. The study supports previous research in which pelleted
feed improved digestibility and provided balanced nutrition in each bite therefore reducing feed consumption but providing energy needed for BW gain. Overall, birds fed the finer particle size (300 microns) had an improved AdjFCR compared to the coarse particle size (600 microns). Interactions between feed form and particle size indicated the finer particle size improved AdjFCR in the mash diets, (1.94) compared to pelleted diets (2.12). Although the finer particle size resulted in improved broiler performance, the gizzard weight of the birds was smaller. Mash feed did produce a larger gizzard weight, but the pelleted fed birds had the higher BW as well as improved AdjFCR.

The results of these experiments indicate that the feed manufacture process can affect the performance of birds in the field and production costs. The results of the particle size study indicated there was no benefit to particle size reduction when the feed was pelleted. Future research is needed on a wider range of particle sizes to determine the optimal range that will benefit the bird but not increase production costs.
Table 1. Experiment 1 broiler diets.

<table>
<thead>
<tr>
<th>Ingredient, %</th>
<th>Starter</th>
<th>Grower</th>
<th>Finisher</th>
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<tbody>
<tr>
<td>Corn</td>
<td>51.66</td>
<td>59.42</td>
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<tr>
<td>Soybean meal (48 % CP)</td>
<td>37.96</td>
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<td>24.88</td>
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<td>Poultry Fat</td>
<td>6.00</td>
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<td>Limestone</td>
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<td>0.99</td>
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<tr>
<td>Dicalcium Phosphate</td>
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<td>DL-methionine</td>
<td>0.16</td>
<td>0.08</td>
<td>0.08</td>
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<td>L-Lysine</td>
<td>0.00</td>
<td>0.03</td>
<td>0.09</td>
</tr>
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<td>Threonine</td>
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<td>0.03</td>
<td>0.07</td>
</tr>
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<td>Salt</td>
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<tr>
<td>Vitamin premix&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
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<tr>
<td>Choline Chloride (60%)</td>
<td>0.20</td>
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<td>0.20</td>
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<td>Trace mineral premix&lt;sup&gt;3&lt;/sup&gt;</td>
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<tr>
<td>Coban&lt;sup&gt;5&lt;/sup&gt;</td>
<td>0.08</td>
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Calculated analysis

<table>
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<th>Starter</th>
<th>Grower</th>
<th>Finisher</th>
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</thead>
<tbody>
<tr>
<td>ME, kcal/kg</td>
<td>3150.00</td>
<td>3200.00</td>
<td>3200.00</td>
</tr>
<tr>
<td>Protein, %</td>
<td>23.00</td>
<td>20.23</td>
<td>18.00</td>
</tr>
<tr>
<td>Ca, %</td>
<td>0.90</td>
<td>0.85</td>
<td>0.80</td>
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<tr>
<td>Available P, %</td>
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<td>0.35</td>
</tr>
<tr>
<td>Lys, %</td>
<td>1.29</td>
<td>1.12</td>
<td>1.00</td>
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<tr>
<td>Met + Cys, %</td>
<td>0.96</td>
<td>0.82</td>
<td>0.77</td>
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</table>

<sup>1</sup>2008 Corn used.

<sup>2</sup>The vitamin premix supplied the following per kilogram of feed: vitamin A, 13,200; cholecalciferol, 3,960 IU; niacin, 110 mg; pantothenic acid 22 mg; riboflavin, 13.2 mg; pyridoxine, 7.9 mg; menadion, 4 mg; folic acid, 2.2 mg; thiamin, 4 mg; and biotin, 0.25 mg.

<sup>3</sup>The mineral premix supplies the following per kilogram of feed: Zn, 120 mg; Mn, 120 mg; Fe, 80 mg; Cu, 10 mg; I, 2.5 mg; Co, 1.0 mg.

<sup>4</sup>Selenium premix provided 0.3 ppm Se.

<sup>5</sup>Monensin was included at 81.65 mg/kg.
Table 2. Experiment 2 broiler diets.

<table>
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<tr>
<th>Ingredient, %</th>
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<th>Grower</th>
<th>Finisher</th>
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<tr>
<td>Corn¹</td>
<td>53.17</td>
<td>60.47</td>
<td>66.38</td>
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<tr>
<td>Soybean meal (48 % CP)</td>
<td>37.44</td>
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<td>24.85</td>
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<td>Poultry Fat</td>
<td>4.97</td>
<td>4.99</td>
<td>4.77</td>
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<td>Limestone</td>
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<td>0.95</td>
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<td>Dicalcium Phosphate</td>
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<td>Choline Chloride (60%)</td>
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<td>Se premix⁴</td>
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<td>Coban⁵</td>
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</table>

Calculated analysis
- ME, kcal/kg: 3035.00, 3100.00, 3150.00
- Protein, %: 22.85, 20.00, 18.00
- Ca, %: 0.90, 0.85, 0.75
- Available P, %: 0.45, 0.40, 0.34
- Lys, %: 1.30, 1.12, 1.10
- Met + Cys, %: 0.94, 0.82, 0.75

¹2009 Corn used.
²The vitamin premix supplied the following per kilogram of feed: vitamin A, 13,200; cholecalciferol, 3,960 IU; niacin, 110 mg; pantothenic acid 22 mg; riboflavin, 13.2 mg; pyridoxine, 7.9 mg; menadion, 4 mg; folic acid, 2.2 mg; thiamin, 4 mg; and biotin, 0.25 mg.
³The mineral premix supplies the following per kilogram of feed: Zn, 120 mg; Mn, 120 mg; Fe, 80 mg; Cu, 10 mg; I, 2.5 mg; Co, 1.0 mg.
⁴Selenium premix provided 0.3 ppm Se.
⁵Monensin was included at 81.65 mg/kg.
Table 3. Actual crude fat and percent of target in Post Pellet Liquid Application (PPLA) Experiments 1 and 2.

<table>
<thead>
<tr>
<th>Treatments&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Experiment 1</th>
<th>Experiment 2</th>
<th>Treatments&lt;sup&gt;1&lt;/sup&gt;</th>
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<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
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<tr>
<td>80</td>
<td>Target</td>
<td>7.7</td>
<td>7.37</td>
<td>6.28</td>
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<tr>
<td></td>
<td>Actual&lt;sup&gt;2&lt;/sup&gt;</td>
<td>6.5</td>
<td>6.2</td>
<td>4.9</td>
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<tr>
<td></td>
<td>% Target&lt;sup&gt;3&lt;/sup&gt;</td>
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<td>85</td>
<td>78</td>
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<tr>
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<td>ME, kcal/kg&lt;sup&gt;4&lt;/sup&gt;</td>
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<td>7.7</td>
<td>7.37</td>
<td>6.28</td>
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<tr>
<td></td>
<td>Actual</td>
<td>7.9</td>
<td>7.4</td>
<td>6.2</td>
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<tr>
<td></td>
<td>% Target</td>
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<td>101</td>
<td>98</td>
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<tr>
<td></td>
<td>ME, kcal/kg</td>
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<td>% Target</td>
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<td>ME, kcal/kg</td>
<td>3300</td>
<td>3321</td>
<td>3273</td>
</tr>
</tbody>
</table>

<sup>1</sup>Treatments consisted of feed that contained 80, 100, and 120% of the target fat by PPLA. The mix treatment contained feed 100% target fat that was applied in the mixer prior to pelleting.

<sup>2</sup>Actual amount of fat that was applied to the feed.

<sup>3</sup>The percent of target that was obtained due to the actual amount of fat applied.

<sup>4</sup>Calculated ME, kcal/kg of feed based on actual crude fat content.
Table 4. Performance of broilers fed different levels of PPLA applied fat in Experiment 1.

<table>
<thead>
<tr>
<th>Treatments⁴</th>
<th>BW¹</th>
<th>AdjFCR²</th>
<th>FI³</th>
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<td></td>
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<td>45 d</td>
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<td>80</td>
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<td>Blended</td>
<td>493</td>
<td>2165</td>
<td>3153</td>
</tr>
<tr>
<td>SEM</td>
<td>8</td>
<td>29</td>
<td>50</td>
</tr>
</tbody>
</table>

Source of Variation

<table>
<thead>
<tr>
<th></th>
<th>0.9504</th>
<th>0.8801</th>
<th>0.9695</th>
<th>0.8760</th>
<th>0.5165</th>
<th>0.3539</th>
<th>0.3180</th>
<th>0.4167</th>
<th>0.4725</th>
</tr>
</thead>
</table>

¹Body Weight (BW) at 14 d, 35 d, and 45 d.
²Feed Conversion Ratio adjusted for mortality (AdjFCR) for intervals 0-14 d, 0-35 d, and 0-45 d.
³Feed intake (FI) from 0-14 d, 0-35 d, and 0-45 d.
⁴Treatments consisted of feed that contained 80, 100, and 120% of the target fat by PPLA. The blended treatment rotated the 80, 100, and 120% diets every time feed was added to the feeders.
Table 5. Performance of broilers fed different levels of PPLA applied fat in Experiment 2.

<table>
<thead>
<tr>
<th>Treatments¹</th>
<th>BW¹</th>
<th>AdjFCR²</th>
<th>FI³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14 d</td>
<td>35 d</td>
<td>42 d</td>
</tr>
<tr>
<td>80</td>
<td>353</td>
<td>2042</td>
<td>2766</td>
</tr>
<tr>
<td>100</td>
<td>355</td>
<td>2033</td>
<td>2749</td>
</tr>
<tr>
<td>120</td>
<td>349</td>
<td>2007</td>
<td>2736</td>
</tr>
<tr>
<td>Mixer</td>
<td>352</td>
<td>1984</td>
<td>2699</td>
</tr>
<tr>
<td>SEM</td>
<td>5</td>
<td>19</td>
<td>21</td>
</tr>
</tbody>
</table>

Source of Variation

| P-Value | 0.9112 | 0.1314 | 0.1703 | 0.6206 | 0.0806 | 0.0210 | 0.0010 | 0.0021 | 0.0830 | 0.3816 | 0.0790 | 0.0869 |

ᵃᵇMeans within a column with different superscripts differ significantly (P ≤ 0.05).

¹Body Weight (BW) of broilers at 14 d, 35 d, 42 d, and 47 d.

²Feed Conversion Ratio adjusted for mortality (AdjFCR) at intervals 0-14 d, 0-35 d, 0-42 d, and 0-47 d.

³Feed intake (FI) at 14 d, 35 d, 42 d and 47 d.

⁴Treatments consisted of feed that contained 80, 100, and 120% of target fat by PPLA. The mix treatment contained feed at 100% target fat that was applied in the mixer prior to pelleting.
Table 6. The composition of the broiler basal starter, grower, and finisher for Experiment 3.

<table>
<thead>
<tr>
<th>Ingredient, %</th>
<th>Starter</th>
<th>Grower</th>
<th>Finisher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>59.30</td>
<td>67.19</td>
<td>71.47</td>
</tr>
<tr>
<td>Soybean meal (48 % CP)</td>
<td>35.80</td>
<td>28.15</td>
<td>23.90</td>
</tr>
<tr>
<td>Limestone</td>
<td>2.09</td>
<td>1.85</td>
<td>1.57</td>
</tr>
<tr>
<td>Dicalcium Phosphate</td>
<td>0.97</td>
<td>1.02</td>
<td>1.07</td>
</tr>
<tr>
<td>DL-methionine</td>
<td>0.00</td>
<td>0.06</td>
<td>0.21</td>
</tr>
<tr>
<td>L-Lysine</td>
<td>0.19</td>
<td>0.13</td>
<td>0.10</td>
</tr>
<tr>
<td>Threonine</td>
<td>0.05</td>
<td>0.00</td>
<td>0.08</td>
</tr>
<tr>
<td>Salt</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Vitamin premix$^1$</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Choline Chloride (60%)</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Trace mineral premix$^2$</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Se premix$^3$</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Coban$^4$</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Poultry Fat</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Calculated analysis

<table>
<thead>
<tr>
<th></th>
<th>Starter</th>
<th>Grower</th>
<th>Finisher</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME, kcal/kg</td>
<td>2935</td>
<td>3016</td>
<td>3068</td>
</tr>
<tr>
<td>Protein, %</td>
<td>23.00</td>
<td>20.00</td>
<td>18.50</td>
</tr>
<tr>
<td>Ca, %</td>
<td>0.90</td>
<td>0.85</td>
<td>0.80</td>
</tr>
<tr>
<td>Available P, %</td>
<td>0.45</td>
<td>0.40</td>
<td>0.35</td>
</tr>
<tr>
<td>Lys, %</td>
<td>1.26</td>
<td>1.10</td>
<td>1.10</td>
</tr>
<tr>
<td>Met + Cys, %</td>
<td>0.96</td>
<td>0.83</td>
<td>0.75</td>
</tr>
</tbody>
</table>

$^1$The vitamin premix supplied the following per kilogram of feed: vitamin A, 13,200; cholecalciferol, 3,960 IU; niacin, 110 mg; pantothenic acid 22 mg; riboflavin, 13.2 mg; pyridoxine, 7.9 mg; menadion, 4 mg; folic acid, 2.2 mg; thiamin, 4 mg; and biotin, 0.25 mg.

$^2$The mineral premix supplies the following per kilogram of feed: Zn, 120 mg; Mn, 120 mg; Fe, 80 mg; Cu, 10 mg; I, 2.5 mg; Co, 1.0 mg.

$^3$Selenium premix provided 0.3 ppm Se.

$^4$Monensin was included at 81.65 mg/kg.
Table 7. Effect of feed form, particle size, and the interaction on BW of male and female broilers in Experiment 3.

<table>
<thead>
<tr>
<th>Treatments&lt;sup&gt;1&lt;/sup&gt;</th>
<th>14 d</th>
<th>21 d</th>
<th>35 d</th>
<th>44 d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Mash + 300</td>
<td>388</td>
<td>373&lt;sup&gt;a&lt;/sup&gt;</td>
<td>772</td>
<td>720</td>
</tr>
<tr>
<td>Mash + 600</td>
<td>358</td>
<td>347&lt;sup&gt;b&lt;/sup&gt;</td>
<td>730</td>
<td>682</td>
</tr>
<tr>
<td>Pellet + 300</td>
<td>470</td>
<td>452&lt;sup&gt;c&lt;/sup&gt;</td>
<td>931</td>
<td>850</td>
</tr>
<tr>
<td>Pellet + 600</td>
<td>454</td>
<td>443&lt;sup&gt;c&lt;/sup&gt;</td>
<td>919</td>
<td>840</td>
</tr>
<tr>
<td>SEM</td>
<td>5</td>
<td>4</td>
<td>10</td>
<td>7</td>
</tr>
</tbody>
</table>

Feed form

| Mash       | 373<sup>a</sup> | 360<sup>a</sup> | 751<sup>a</sup> | 701<sup>a</sup> | 1827<sup>a</sup> | 1567<sup>a</sup> | 2733<sup>b</sup> | 2239<sup>a</sup> |
| Pellet     | 462<sup>b</sup> | 447<sup>b</sup> | 925<sup>b</sup> | 845<sup>b</sup> | 2215<sup>b</sup> | 1864<sup>b</sup> | 3227<sup>b</sup> | 2616<sup>b</sup> |
| SEM        | 5    | 4    | 8    | 6     | 20   | 12    | 26   | 19   |

Particle Size

| 300        | 429<sup>a</sup> | 412<sup>a</sup> | 851<sup>a</sup> | 785<sup>a</sup> | 2038 | 1718    | 2981 | 2440 |
| 600        | 406<sup>b</sup> | 395<sup>b</sup> | 824<sup>b</sup> | 761<sup>b</sup> | 2004 | 1713    | 2979 | 2415 |
| SEM        | 12   | 12   | 24   | 19    | 54   | 41      | 70   | 53   |

Source of variation

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>14 d</th>
<th>21 d</th>
<th>35 d</th>
<th>44 d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form x Size</td>
<td>0.1451</td>
<td>0.0422</td>
<td>0.1634</td>
<td>0.0651</td>
</tr>
<tr>
<td>Feed form</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td>Particle Size</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0185</td>
<td>0.0040</td>
</tr>
</tbody>
</table>

<sup>a,b,c</sup>Means within a column with different superscripts differ significantly ($P \leq 0.05$).

<sup>1</sup>Treatments consist of mash diets with 300 and 600 microns particle size and pelleted diets with 300 and 600 microns particle size.
Table 8. Effect of feed form, particle size, and the interaction on feed intake of broilers in Experiment 3.

<table>
<thead>
<tr>
<th>Treatments¹</th>
<th>14 d</th>
<th>21 d</th>
<th>35 d</th>
<th>44 d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mash + 300</td>
<td>1289</td>
<td>2540&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6198&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9663&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mash + 600</td>
<td>1380</td>
<td>2845&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6916&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10443&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pellet + 300</td>
<td>1305</td>
<td>2724&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>7028&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10936&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pellet + 600</td>
<td>1300</td>
<td>2716&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6960&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10741&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>SEM</td>
<td>25</td>
<td>43</td>
<td>94</td>
<td>142</td>
</tr>
</tbody>
</table>

Feed form

<table>
<thead>
<tr>
<th>Feed form</th>
<th>14 d</th>
<th>21 d</th>
<th>35 d</th>
<th>44 d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mash</td>
<td>1334</td>
<td>2692</td>
<td>6557&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10053&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pellet</td>
<td>1303</td>
<td>2720</td>
<td>6994&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10839&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>SEM</td>
<td>19</td>
<td>41</td>
<td>93</td>
<td>122</td>
</tr>
</tbody>
</table>

Particle Size

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>14 d</th>
<th>21 d</th>
<th>35 d</th>
<th>44 d</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>1297</td>
<td>2632&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6613&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10299</td>
</tr>
<tr>
<td>600</td>
<td>1340</td>
<td>2780&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6938&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10592</td>
</tr>
<tr>
<td>SEM</td>
<td>18</td>
<td>36</td>
<td>101</td>
<td>155</td>
</tr>
</tbody>
</table>

Source of variation

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form x Size</td>
<td>0.0613</td>
</tr>
<tr>
<td>Feed form</td>
<td>0.0016</td>
</tr>
<tr>
<td>Particle Size</td>
<td>0.0004</td>
</tr>
</tbody>
</table>

<sup>abc</sup>Means within a column with different superscripts differ significantly \((P \leq 0.05)\).

¹Treatments consist of mash diets with 300 and 600 microns particle size and pelleted diets with 300 and 600 microns particle size.
Table 9. Effect of broilers feed form, particle size, and the interactions on adjusted feed conversion ratio (AdjFCR) in Experiment 3.

<table>
<thead>
<tr>
<th>Treatments 1</th>
<th>0-14d</th>
<th>0-21d</th>
<th>0-35d</th>
<th>0-44d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mash + 300</td>
<td>1.69</td>
<td>1.70</td>
<td>1.80</td>
<td>1.94</td>
</tr>
<tr>
<td>Mash + 600</td>
<td>1.96</td>
<td>2.01</td>
<td>2.07</td>
<td>2.11</td>
</tr>
<tr>
<td>Pellet + 300</td>
<td>1.42</td>
<td>1.53</td>
<td>1.73</td>
<td>1.87</td>
</tr>
<tr>
<td>Pellet + 600</td>
<td>1.45</td>
<td>1.54</td>
<td>1.70</td>
<td>1.84</td>
</tr>
<tr>
<td>SEM</td>
<td>0.03</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Feed form

<table>
<thead>
<tr>
<th>Feed form</th>
<th>0-14d</th>
<th>0-21d</th>
<th>0-35d</th>
<th>0-44d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mash</td>
<td>1.83</td>
<td>1.86</td>
<td>1.93</td>
<td>2.03</td>
</tr>
<tr>
<td>Pellet</td>
<td>1.43</td>
<td>1.54</td>
<td>1.71</td>
<td>1.85</td>
</tr>
<tr>
<td>SEM</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Particle Size

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>0-14d</th>
<th>0-21d</th>
<th>0-35d</th>
<th>0-44d</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>1.55</td>
<td>1.62</td>
<td>1.76</td>
<td>1.90</td>
</tr>
<tr>
<td>600</td>
<td>1.70</td>
<td>1.78</td>
<td>1.88</td>
<td>1.97</td>
</tr>
<tr>
<td>SEM</td>
<td>0.06</td>
<td>0.05</td>
<td>0.04</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Source of variation

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form x Size</td>
<td>0.0022</td>
</tr>
<tr>
<td>Feed form</td>
<td>0.0001</td>
</tr>
<tr>
<td>Particle Size</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

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

1 Treatments consist of mash diets with 300 and 600 microns particle size and pelleted diets with 300 and 600 microns particle size.
Table 10. Percentage fines and Pellet Durability Index (PDI) of the pelleted treatments in Experiment 3.

<table>
<thead>
<tr>
<th>Diets</th>
<th>P300</th>
<th></th>
<th></th>
<th>P600</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fines(^1)</td>
<td>PDI(^2)</td>
<td>%</td>
<td>Fines(^1)</td>
<td>PDI(^2)</td>
</tr>
<tr>
<td>Starter</td>
<td>15</td>
<td>89.8</td>
<td>17</td>
<td>86.4</td>
<td></td>
</tr>
<tr>
<td>Grower</td>
<td>22</td>
<td>84.6</td>
<td>27</td>
<td>81.6</td>
<td></td>
</tr>
<tr>
<td>Finisher</td>
<td>6</td>
<td>87.2</td>
<td>8</td>
<td>84.0</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Measured with a US No.5 sieve.
\(^2\) Pellet Durability Index (PDI) is measured as 500 g whole pellets, tumbled for 10 min, and then the amount of whole pellets left in g / 500 g of whole pellets.
\(^3\) The starter, grower and finisher basal diets.
Table 11. Effect of gizzard weight (g) and percentage gizzard in Experiment 3 at 44 d.

<table>
<thead>
<tr>
<th>Treatments&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Gizzard weight (g)&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Gizzard as g/100g BW&lt;sup&gt;3&lt;/sup&gt;</th>
<th>P-Value&lt;sup&gt;5&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>M300</td>
<td>35.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.45&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>M600</td>
<td>38.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.56&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>P300</td>
<td>26.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.05&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>P600</td>
<td>33.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.30&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

Source of Variation: 0.0108  0.0387

<sup>1</sup>Treatments consist of mash diets with 300 and 600 microns particle size and pelleted diets with 300 and 600 microns particle size.

<sup>2</sup>Weight of gizzard in grams (g).

<sup>3</sup>Gizzard as g/100g BW.