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Feed Quality Effects on Modern Heavy Broiler Performance

Robert Benjamin Sellers

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By

Robert Benjamin Sellers

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By

Robert Benjamin Sellers

Approved:

_____

Kelley G. S. Wamsley
(Major Professor)

_____

Christopher D. McDaniel
(Committee Member/Graduate Coordinator)

_____

Joseph S. Moritz III
(Committee Member)

_____

George M. Hopper
Dean
College of Agriculture and Life Sciences

Name: Robert Benjamin Sellers

Date of Degree: December 11, 2015

Institution: Mississippi State University

Major Field: Agriculture

Major Professor: Kelley G. S. Wamsley

Title of Study: Feed quality effects on modern heavy broiler performance

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Candidate for Degree of Master of Science

Commercial broilers are fed exclusively pelleted diets; this is due to research that has demonstrated numerous benefits to feeding pellets. The first objective was to investigate the effects of modest improvements in pellet quality on two modern broiler strains. Regardless of strain, feeding 80% pellets improved broiler performance from d 28 to 42. The second objective was to investigate the effects of feed form and liquid application method on feed augering segregation and subsequent broiler performance. In general, percent pellets steadily decreased across location throughout feed augering. Also, phytase segregation occurred throughout augering and was exacerbated in post-pellet liquid application diets. When the augered diets were fed to broilers, 75% pellets and post-pellet liquid application diets improved performance. The final objective was to investigate the change in percent pellets as feed was augered throughout an entire commercial poultry house. Ultimately, creating high-quality pellets decreases pellet attrition and improves broiler performance.

Keywords: pellet quality, nutrient segregation, feed augering, broiler performance, commercial broiler strain

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CHAPTER I

LITERATURE REVIEW

The Modern Commercial Broiler

The broiler chicken in today's industry is much different from past genotypes. Over 8000 years ago, the red junglefowl (*Gallus gallus*) was first domesticated in Asia [1]. This domesticated subspecies, *Gallus gallus domesticus*, is representative of all chickens, including broilers (meat producing birds) and layers (egg producing birds) [2]. Due to their ability and efficiency to produce meat and eggs, chicken is one of the most consumed sources of animal protein in the world. This is especially important due to our world's growing population. Through significant advancements in genetic selection, nutrition, and research, the poultry industry is much different from its rather modest beginnings.

In the early 1940s, genetic selection in broilers was a relatively new idea. Initially, poultry breeders selected for rapid, large growth. However, this selection was based solely upon the individual weight of a particular bird and was referred to as "mass selection" [3]. The process of mass selection gradually transformed over time into more descriptive selection criterion, such as reproductive traits, egg production, and hatchability [3]. As the genetic selection continued to develop, broiler breeds were crossed and desirable traits were carried on, which eventually led to the commercially available broiler strains of today.

The modern broiler genotype has made tremendous strides when compared to early broiler crosses [4-7]. Research has demonstrated that genetic selection at the primary breeding level has attributed to 85-90% of growth rate improvements, while nutrition has accounted for 10-15% [4, 8-9]. Through genetic selection and nutrition, modern genotypes are able to convert feed into weight gain in a highly efficient manner [7]. Furthermore, genetic improvements in the past 20 years alone have demonstrated increased performance amongst modern genotypes. In 2006, Fancher [8] reported that d 42 body weight had improved by 0.55 kg per year for 10 years (1996 to 2006). In addition to improved weight gain and feed conversion, modern broiler genotypes amass large amounts of muscle, which equates to high yield of consumable chicken meat [6, 7]. Although there have been substantial differences noted between early and modern genotypes, not all modern strains possess the same traits (i.e. weight gain, feed conversion, meat yield) to the same extent. Research has demonstrated significant differences in body weight, feed conversion, and carcass yield between modern strains; however, there is yet to be one strain that performs better in all three categories [10]. This can be supported by past literature, which has demonstrated that phenotypic variation may be a result of intense directional selection because genotypes with high selection probability are passing down high variability [11, 12].

Advances in modern genetics, nutrition, and research have allowed modern broilers to become more capable of meeting or exceeding their target weights in substantially less time than previous years [5]. The improved feed conversion achieved by the modern broiler makes it one of the most efficient sources of animal protein production [13]. In addition, some markets grow broilers for long periods of time

(sometimes up to 9+ weeks of age); thus, broilers are becoming heavier and heavier. From a nutritional standpoint, research has demonstrated that the nutrient requirements of modern broilers, as well as heavy broilers, have changed from past genotypes.

Research has also demonstrated that adjustments in nutritional requirements such as dietary energy, digestible amino acids, vitamins, and minerals can help maximize heavy broiler growth potential and meat yield [14-17]. Furthermore, the quality of feed produced may have an impact on modern broilers. Early feed quality research has established that feeding pelleted vs. mash diets improves broiler performance [18-20]. In addition, it has been determined that incrementally increasing percent pellets within a diet can positively affect broiler performance [20-23]. These researchers determined that feeding pellets was beneficial to broiler growth and development; however, no research has investigated the effects of slight improvements in percent pellets across multiple strains of modern heavy broilers.

In summary, modern broilers are much different than early genotypes. The ability of the modern broiler to efficiently convert feed to weight and muscle gain is remarkable when compared to earlier broiler models. It can be concluded that improvements in genetic selection, nutrition, and research have made the poultry industry a highly efficient and profitable enterprise.

Poultry Production

Poultry production in the United States is one of the most successful enterprises in agriculture. In 2014, the poultry market produced over $48.2 billion of sales in the United States, and over 68% ($32.7 billion) of sales were attributable to broiler production [24]. In general, the value of poultry production increased by 9% from 2013

to 2014 [24]. This increase demonstrates the ever-increasing growth and efficiency of poultry production in the United States.

This efficiency is achieved through vertical integration used by most commercial poultry producers. Through vertical integration, biosecurity and quality assurance are enhanced as commercial producers can provide their own chicks and feed to contracted growers. Additionally, vertical integration can provide a measure of quality assurance for final processed products as the chance for cross-contamination is reduced.

As a part of vertical integration, contracted growers are used. Growers are company specific, and companies provide growers with detailed protocols for the management and bird husbandry. Contract growers are responsible for carrying out husbandry and welfare of broilers during a grow-out period. In addition, growers are responsible for all upkeep and cost associated with house management, energy, and facilities. Contract growers are compensated by the integrator for pounds of live weight produced, and generally, companies offer bonuses for the low feed conversion (amount of feed consumed to weight gain).

Mississippi Poultry Production

Poultry is the largest agricultural commodity in Mississippi [25]. In 2014, the value of Mississippi agricultural production was $7.9 billion [25], and broiler production accounted for $2.8 billion in sales (35% of all agricultural production) [24]. The top broiler producing states were Georgia, Alabama, Arkansas, North Carolina, and Mississippi at 1324.2, 1061.5, 969.8, 795.2, and 727.2 million head, respectively [24].

While broiler production is prevalent throughout the whole state, central counties of Smith, Neshoba, Scott, and Leake produce the most value in broiler production. In

addition, Mississippi is home to the largest table egg producer (Cal-Maine, Inc.) and 3rd largest broiler producer (Sanderson Farms, Inc.) in the United States [26].

Poultry Feed Manufacture

Feed and feed manufacture represent a significant cost (60-70%) to broiler production. These costs are driven by ingredient price and subsequent formulation, manufacturing specifications, and feed volume requirements necessary to satisfy broiler production goals [27]. Therefore, it is crucial that poultry diets are cost-effective while still meeting the nutritional requirements of the broiler. In addition, the quality of feed produced should be of importance due to the benefits extended to broiler performance.

Diet Formulation

In order to maximize growth potential, broilers need an adequate source of energy, protein, vitamin, and mineral added in the diet. These nutrients are sourced from a variety of ingredients, such as cereal grains, oilseed meals, animal by-product blends, and dietary fat [28]. Typical U. S. diets are comprised of approximately 60-70% corn and soybean meal. In order to meet energy requirements, most diets are formulated with corn and dietary fat (i.e. animal fat, vegetable fat) [28]. Soybean meal is a common oilseed meal that provides around 48% crude protein in the diet [28]. Animal by-products blends, such as meat and bone meal, are often used to provide an extra source of amino acids, as well as calcium and phosphorus [28]. In addition, broilers need macro minerals such as calcium and inorganic phosphate to support and maintain growth [28]. The effects of phosphorus, as well as phytase will be discussed later in this literature

review. Trace minerals, vitamins, and amino acid supplements are also supplemented in the diet to help promote overall growth and development [28].

Furthermore, the dietary inclusion of these ingredients depend on their nutritional composition, price, and availability. In the past, commercial diets were formulated to meet total amino acid requirements of the bird; however, due to advancements in nutrition and research, commercial nutritionists are now able to formulate on a digestible amino acid basis (i.e. amino acids that can actually be used by the bird). This can help provide a more accurate estimation of the bird's needs, but does require an accurate nutrient profile of each ingredient in order to correctly formulate.

In addition, most commercial diets are formulated on a least-cost basis, which allows for the broiler's nutritional requirements to be met in a cost-effective manner. However, formulating based on least-cost can result in the inclusion of ingredients that may be highly variable in nutritional content. Although these diets are formulated to meet the broiler's nutritional requirements, the variability in least-cost ingredients may cause for over- or under-formulation. Least-cost formulation may also have negative implications on feed quality, which will be discussed later in this literature review.

Mixing

Mixing is an integral part of feed manufacture. In order to provide maximum benefit to the bird, ingredients need to be mixed uniformly throughout the diet [29]. In other words, mixing should equally distribute nutrients throughout the diet in a similar fashion. Mixer uniformity is established as a coefficient of variation (CV). In the commercial feed industry, a mixer CV below 10% is acceptable [29, 30]. To establish mixer CV, easily identifiable traceable markers are added to the diet [30]. Mash feed

samples are taken after diets have been mixed, and these samples are analyzed for the traceable marker added to the diet [30].

Mixing feed properly can result in improved bird performance, especially in young chicks [31]. McCoy and coauthors [31] determined that lowering mixer CV (<10% CV) reduced feed conversion and improved performance in broiler chicks; ultimately, McCoy [31] concluded that mixer uniformity is essential especially in young animals due to their lower feed intake. Conversely, poor mixer uniformity can cause the segregation of nutrients. This could cause poor performance and broiler uniformity, as well as toxicity or deficiency of nutrients.

Pelleting

The most capital enterprise of feed manufacture is the pelleting process, as the cost to produce pellets in an integrated feed mill has been estimated at $3 to $4 per ton [32]. In recent times, broilers have been fed exclusively pelleted rations. The benefits of feeding pellets are well documented in literature [18-20, 22, 33-35]; research has demonstrated that feeding pellets improves handling characteristics and productive energy [18, 20, 33, 35], decreases feed spillage and wastage [18, 33, 35], improves hygienic quality [35], reduces nutrient segregation [33, 35], increases feed intake [21], and ultimately, improves live weight gain and broiler performance [21, 22, 33, 34]. These benefits improve as pellet quality improves.

Pellet Quality and Broiler Performance

Pellet quality can be defined as how durable a pellet is to intense handling and transportation from the feed mill to point of consumption. Pellet quality can be measured

by pellet durability index (PDI) [36], modified pellet durability index (MPDI) [36], and surviving pellets [37]. Each of these measures (PDI, MPDI, and surviving pellets) are adequately described within the corresponding references. Percent pellets (pellet to fine ratio within a diet) can also be a way to measure pellet quality; however, it does not directly correlate to PDI or surviving pellets.

Moreover, the live performance benefits associated with feeding pellets can be further improved by feeding pellets of high-quality [21, 23, 33, 38]. Schiedeler [33] found that feeding 75% pellets reduced feed conversion when compared to birds fed 25% pellets. Cutlip and cohorts [38] determined that feeding broilers high-quality pellets (94 PDI) reduced feed conversion ratio when compared to broilers fed a 4 percentage point lower PDI (90). In addition, Lilly et al. [21] determined that every 10 percentage point increase in percent pellets would provide a 0.4 point reduction in FCR, 10 g increase in carcass weight, and 4 g increase in breast weight. These data suggest that differences in pellet quality can significantly impact broiler performance.

Ultimately, pellet quality can affect the percentage of pellets in a diet or in a feed pan. However, to our knowledge, there is little replicated research that has documented the effects of feed augering on pellet quality and percent pellets. Previous field research has demonstrated that pellet quality can be negatively affected by feed augering [33, 39]. In a 1991 field study conducted by Schiedeler [33], it was determined that some feed pans were only receiving 30% pellets available for broiler consumption. More recently, a collaborative field study conducted by Mississippi State and West Virginia University demonstrated that percent pellets decreased throughout augering and slightly increased at the end of the feed line [39]. Additionally, nutrients, especially phytase, segregated

based on manufacturing technique. These data suggest that broilers may not be receiving an adequate amount of pellets nor nutrients in the feed pan. Therefore, the detriment to pellet quality and subsequent nutrient segregation that occurs during feed augering may affect broiler performance and uniformity depending on the feed pan location.

While the relationship between feed augering and pellet attrition is not clearly defined in literature, it is possible that shear force and shear velocity can play a key role in the process of pellet distribution and attrition as feed is augered throughout a commercial poultry house. Shearing force occurs when the top of an object is pushed one direction, while the bottom is forced in the opposite direction [40]. It is likely that shearing force and translational shearing velocity can be increased or decreased by variations in an auger motor (i.e. horsepower, revolutions per minute, etc.) and the amount of feed (and pellets) within the feed line. For example, if a feed line motor turns the auger at a rapid rate, velocity and force will increase; hence, there is more opportunity for the pellet to be destroyed. This may affect both broiler performance and uniformity due to increased fines and nutrient segregation.

In conclusion, it has been established through research that feeding high-quality pellets can be beneficial to broiler performance [21-23, 38]; however, there have been some limitations to this research. For example, studies have investigated broad variations in feed form that may not adequately describe the optimal pellet quality necessary to maximize broiler performance. In addition, the previously tested feed forms (i.e. 90% pellets) may not represent a feasible quality attainable by a commercial feed mill due to the cost associated with creating these high-quality pellets. Furthermore, the effects of feed form have not been established on modern heavy broilers (42+ days of age) and only

one strain has been evaluated at a time. Also, there is a need for replicated research on the effects of feed augering on nutrient segregation. Due to the findings of Mississippi State and West Virginia University [39], future research is warranted to determine if pellet quality and nutrient segregation will effect heavy broiler performance.

Factors Affecting Pellet Quality and Nutrient Availability

The pelleting process has been defined as "the agglomeration of small particles into larger particles by means of a mechanical process in combination with moisture, heat, and pressure" [41]. The majority of heat and moisture associated with the pelleting process is due to steam conditioning. When mash feed passes through a steam conditioner, saturated steam and heat are applied to prepare the feed for processing. In general, higher steam conditioning temperatures (200-205°F; 93-96°C) improve pellet quality [38, 42] due to increased starch gelatinization, as well as protein denaturation and gelation [42]. Starch gelatinization occurs when water is diffused into a starch granule, is heated, and leaches amylose. When the gelatinized amylose and amylopectin starch chains cool, an ordered structure forms and binds feed particles [43]. However, Briggs [44] determined that protein plays the biggest role in binding feed particles and creating durable pellets. Proteins are denatured through thermal processing, causing protein gelation [45] and subsequent pellet formation. While protein denaturation is helpful in creating pellets, it can potentially be harmful to nutrients such as amino acids and enzymes [42, 46, 47]. Amino acids and exogenous enzymes can be denatured because of increased cross-linking or Maillard reactions due to high temperature and moisture [46].

Another factor that can affect pellet quality and nutrient availability is the manner in which supplemental fat is added to the diet. Fat is included in broiler diets to provide a

dense source of dietary energy. Research has demonstrated higher inclusions of mixer-added fat (> 2.2% vs. 1.0%) can result in decreased pellet quality [42, 46, 47]; however, these increased fat inclusions can maintain exogenous enzyme efficacy [46] and amino acid digestibility [42, 47]. The adverse relationship demonstrated between pellet quality and nutrient availability when mixer-added fat was observed could be due to a number of factors. In general, fat coats feed particles [48, 49] and deters the water and heat that cause starch gelatinization and protein denaturation/gelation; thus, decreasing the agglomerative properties of the feed without harming nutrients. Furthermore, dietary fat acts as a lubricant between the mash and pellet die [50]. With fat coating the feed particles, the frictional and mechanical heat decrease, thus decreasing the chance for protein denaturation. Additionally, increased mixer-added fat can decrease the energy required to run a pellet mill as well as increase throughput [42, 46].

Due to an increased demand for feed volumes, throughput is of concern to production managers and feed manufacturers alike. Often times, the need for feed supersedes the throughput rate necessary to provide high-quality pellets. Research conducted by Buchanan and cohorts [51] determined that pellet quality was improved using a thick pellet die (4.76 x 44.96 mm) run slowly (0.75 tonne/h) vs. thin pellet die (4.76 x 38.10 mm) run fast (1.14 tonne/h). Pellet quality is impacted by production rate and die thickness due to mash retention time within the pellet die. As the mash feed remains in the die longer, it allows for better agglomeration of feed particles [51]. Although die retention time can improve pellet quality, commercial feed mills will often sacrifice pellet quality in order to save on feed costs due to the substantial increase in energy usage associated with longer milling periods.

In conclusion, the pelleting process is complex. It is often times challenging to create a diet of high pellet quality without harming nutrient availability, and vice versa. Furthermore, as the main concern for commercial feed manufacturers is the amount of feed produced, many manufacturers are not aware that nutrient availability can be compromised during the pelleting process. However, if diets of both high-pellet quality and nutrient availability were to be fed, the cost to manufacture the feed may be justified by the presumable improvements in performance and carcass traits [21, 23, 38].

Phytase as an Exogenous Feed Enzyme

Phosphorus and Phytate

Phosphorus is an essential mineral required by all animals [52]. This mineral helps regulate cellular mechanisms and aids in bone development, as almost 85% of phosphorus in the body is stored in the bone [52]. Typical United States broiler diets contain approximately 60-70% is comprised of corn and soybean meal. These ingredients contain phosphorus; however, the vast majority of phosphorus stored in these ingredients are bound by the phytate molecule [53]. Phytate (myo-inositiol hexaphosphoric acid) is the storage form of phosphorus in plants [54], but phytate-bound phosphorous cannot be digested by poultry; thus, phosphorus must be presented in the form inorganic phosphate [55]. This problem can be handled in a couple of ways: supplementing inorganic phosphates or feeding exogenous phytase enzymes [55]. The first, supplementation of inorganic phosphates, is an effective yet expensive program to employ due to the lack of renewability. The other solution is the supplementation of an exogenous phytase enzyme, which can release phosphorus from phytate [55].

Phytase Enzymes

Exogenous phytases have been used commercially since the 1970s in an effort to release phosphorus from phytate and improve broiler performance [55]; this is due to the low levels of endogenous phytase are found in monogastrics [53, 55]. Phytase has the ability to release phosphorus from phytate by hydrolyzing one or more phosphate groups on the phytate ionstitol ring [54]. Phytase can hydrolyze the phosphate group in the 3- or 6 position. Therefore, exogenous phytase enzymes are included in the diet to improve nutrient availability [56].

Endogenous phytase enzymes can be derived from a number of different sources, including yeast, plant seeds, and microorganisms, such as *E. coli* and *A. niger* [57]. The inclusion of phytase in poultry diets has been demonstrated to substantially increase available phosphorus and improve broiler performance [58-60]. The supplementation of phytase can also reduce the overfeeding of dietary phosphorus [52]. When phytase is included in a poultry diet, it can spare calcium and phosphorus inclusions. Also, supplementing exogenous phytase can help decrease the phosphorus content in poultry litter, which has been associated with eutrophication and consequential environmental impact [61]. Moreover, feeding unconventionally high inclusions of phytase (super-dosed; 3-4x recommended dosage) can add further value to meat yield, weight gain, and FCR by quickly destroying all of the phytate present in the diet, releasing phosphorus, and improving gut health [62, 63].

Phytase Testing and Application

When determining the retention of an exogenous phytase, the AOAC 2000.12 [64] method is generally used in a commercial lab to obtain *in vitro* activity. However,

this method may not adequately describe the efficacy of phytase *in vivo* [65]. If phytase is added in the mixer, the heat, moisture, and pressure associated with the pelleting process may cause the phytase to be denatured. Loop et al. [65] determined that the efficacy of genetic variants of *E. coli*-derived phytase added in the mixer were better described *in vivo*, as *in vitro* efficacy did not necessarily translate to improved bird performance.

Phytase can be supplemented in granular or liquid form. Granular phytase is added in the mixer; however, as previously mentioned, some phytase enzymes have the potential to be denatured. In effort to protect mixer-added phytase from denaturation, granular phytase can be encapsulated by a coating, such as a carbohydrate-lipid [66]. However, too much coating can decrease efficacy because phytase cannot be released into the gastrointestinal tract [66]. Another method to preserve enzyme efficacy is the use of a liquid phytase added post-pelleting to help ensure that the enzyme activity is not compromised during the manufacturing process. However, additional equipment (i.e. post-pellet applicator) is required, and uniform application of the enzyme is of concern [65]. In addition, liquid phytase added post-pelleting is generally incorporated with post-pellet fat application. However, post-pellet fat application involves less mixer-added fat; once again, this creates concern for potential protein/enzyme denaturation [42, 46, 47].

In summary, the phytase enzyme is an extremely helpful tool to the poultry industry. The supplementation of phytase in poultry diets can improve performance by making more nutrients available to the bird, such as inorganic phosphate and calcium. When choosing a phytase, the efficacy should be tested *in vivo* in order to ensure that broiler performance is maximized.

Conclusions

Through improvements in genetic selection, nutrition, and research, the poultry industry has made tremendous strides. Over the years, broilers have become highly efficient creatures capable of producing large amounts of lean meat protein quickly. This efficiency is especially important in today's industry, as many broilers are grown for much longer periods of time. From a nutritional standpoint, researchers are constantly investigating the optimal nutrient needs of the modern broiler; however, feed quality is far less researched. Feeding pelleted diets of high-quality could potentially be very beneficial to the modern broiler, especially heavy broilers, as these birds have been selected to maximize growth through feed intake.

Furthermore, it has been demonstrated through field research that nutrients segregate throughout feed augering based upon pellet quality and manufacturing technique [33, 39]. Although there are many ways to improve pellet quality, it may be challenging for feed manufacturers to determine a target pellet quality without understanding the effects of transportation and feed augering on pellet attrition, nutrient segregation and subsequent heavy broiler performance. As commercial nutritionists are formulating diets to optimize broiler growth, it is of no use if broilers are not receiving the intended nutrients.

In closing, research is warranted to determine how pellet quality and the changes therein can affect modern heavy broiler performance and carcass characteristics. As pellet quality has been demonstrated to impact the segregation of nutrients, it is likely that modern heavy broilers will perform better when fed high-quality pellets. All in all, previous feed form research may not adequately describe the effects of pellet quality on

modern day broiler performance due to the vast genetic improvements in modern broiler genotypes and the recent addition of the heavy broiler market.

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CHAPTER II

THE EFFECTS OF STRAIN AND INCREMENTAL IMPROVEMENTS IN FEED FORM ON D 28-49 MALE BROILER PERFORMANCE

Summary

Feeding high-quality pellets to modern commercial broilers may maximize genetic potential; however, this typically requires an increased cost to produce feed. Therefore, it is important to determine if incremental improvements in feed form (FF) can increase performance of modern broiler strains. The current study was conducted to investigate the effects of feeding modest improvements in feed form (50, 60, 70, or 80% intact pellets; IP) to two commercial broiler strains (Strain A or B) on d 28 to 42 and d 28 to 49 growth performance and processing variables. A common diet was manufactured to contain 80% IP, of which a portion was ground to create a total of four FF treatments varying in IP to ground pellet ratios: 50:50; 60:40; 70:30; and 80:20. Strain A demonstrated improvements in BW, BWG, and FCR when compared to Strain B. For the main effect of FF, feeding 80 vs. 50% IP reduced d 28 to 42 FCR. Also, feeding birds 80% IP vs. all other FF treatments improved d 28 to 42 BWG and d 42 BW. A Strain x FF interaction established that Strain A broilers fed 50, 60, and 70% IP diets had higher d 43 total breast yield than Strain B birds fed the same FF treatments; however, both strains demonstrated similar total breast yield when 80% IP were fed. On d 49, Strain B BW was not affected by FF. Performance (d 28 to 49) was potentially altered due to

removing 4 birds/pen for processing on d 43, which decreased feeder competition. Nonetheless, data suggests a distinct benefit for feeding improved FF from d 28 to 42 to modern broilers. More research is warranted using heavy broilers (d 28 to 49).

Keywords: feed form, pellet quality, bird strain, commercial, bird performance, processing

Description of Problem

Feed and feed manufacture represent a significant cost (60-70%) to the commercial broiler industry. These birds are fed exclusively pelleted diets due to research that has confirmed the positive impact of pellets on broiler performance [1-8]. These improvements include decreased ingredient/nutrient segregation, improved handling characteristics, reduced feed spillage, as well as decreased time and energy spent eating associated with prehension of feed [1-2, 5, 8].

When broilers are fed diets containing high-quality pellets, live performance benefits can become even greater [9-12]. Consequently, the economic return associated with the aforementioned benefits are likely to increase as pellet quality increases [10]. Research has documented the positive impact of broad ranges of pellet quality on modern day broiler performance [10, 11]. In addition, the feed form (FF) tested in previous research may not represent a quality that may be produced in a commercial mill due to throughput demands and increased costs associated with creating high-quality pellets (i.e. 90% intact pellets:10% fines). Therefore, there is a need to determine if a modest improvement range of pellet quality can elicit an incremental improvement in broiler performance. This would provide feed manufacturers with the information to make an

educated decision on whether or not the investment in feed quality is cost-effective, depending upon their operation.

Another factor that has not been investigated in recent literature is the sensitivity of current broiler strains to varying FF. Previous research has only utilized one strain of broiler at a time when investigating bird response to feed form [6-11]. However, research has demonstrated significant differences in overall BW, feed intake (FI), and carcass yield between fast-growing and high-yield strain crosses [13]. Due to genetic selection of the modern broiler strain, it is possible that diets varying in FF could further elicit performance differences between multiple broiler strains, especially in the heavy broiler market (>3.5 kg). Therefore, the objective of the current study was to investigate the sensitivity of two different modern broiler strains (Strain A or B) to incremental and commercially attainable improvements in FF (50, 60, 70, or 80% intact pellets; IP) over two (d 28 to 42 and 28 to 49) grow-out periods.

Materials and Methods

Pretest Period Broiler Management (d 0 to 28)

A total of 1728 day old male chicks (864/strain) were obtained from commercial hatcheries [14, 15] and were equally allotted by strain in 96 floor pens (0.91 x 1.22 m; 18 birds/pen; 0.06 m^2/bird) at the Mississippi State University Poultry Research Unit. Strain A chicks were vent-sexed at the hatchery, while Strain B chicks were feather-sexed upon arrival to Mississippi State. The solid-walled grow-out house had forced-air heating and evaporative cooling cells. Cross-ventilation was achieved by negative air pressure. In each pen, built-up litter was used; a hanging feeder (16.0 kg capacity) and 3 nipple drinkers were available for *ad libitum* feed and water consumption.

All birds were fed a common starter and grower broiler diet formulated to meet or exceed breeder recommendations for each strain [16, 17] from d 0 to 28. These pre-test diets were manufactured at the Mississippi State University Poultry Research Unit and contained corn, soybean meal, distiller's dried grains with solubles, and meat and bone meal. The starter diet was fed from d 0 to 14 as crumbles and the grower diet was fed from d 15 to 28 as pellets.

The lighting and temperature schedule were designed to encompass both strain recommendations [18, 19]. Birds received 24 h of light from d 0 to 7 and 18.5 h of light from d 7 to 49. Lighting was set to 26.9 lux from d 0 to 10. On d 10, lighting intensity was incrementally decreased until 2.7 lux was reached on d 21. The lighting intensity was 2.7 lux for the remainder of the grow-out period (d 21 to 49). On d 0, ambient house temperature was 32.7°C; temperature was incrementally decreased until 16.1°C was achieved on d 49.

Experimental Diet Preparations

Batching

Experimental finisher 1 (d 28 to 42) and finisher 2 (d 42 to 49) diets were manufactured at the West Virginia University pilot feed mill [20]. These practical diets were nutritionally common; ingredients utilized included corn, soybean meal, distiller's dried grains with solubles, and meat and bone meal. Similar to the starter and grower period, diets were formulated to meet or exceed breeder recommendations for each broiler strain (Table 1) [16, 17]. Diets were each batched and mixed in a 0.907-tonne vertical screw mixer [21] for 10 minutes dry and 10 post fat addition, prior to pelleting.

Feed manufacture

To help ensure that nutrient availability and enzyme retention was not compromised [22-24], all fat was added at the mixer; diets were steam conditioned for 10 seconds at 81°C with an incoming steam pressure of 262 kPa. All diets were subsequently pelleted through a 38.10 x 4.76 mm pellet die at a production rate of 0.986 tonne/h (Finisher 1) and 0.977 tonne/h (Finisher 2). After pelleting, a representative 22.7 kg sample from the finisher 1 and 2 diet was sifted using a No. 6 American Society for Testing and Materials screen [25] to determine the pellet to fine ratio of the diet created (Table 2.1).

The finisher 1 diet (3628.7 kg total) was evenly divided into four 907.2 kg allotments; every fifth feed bag containing 22.7 kg was ground via hammer mill to produce ground pellets (GP) for the creation of different pellet qualities that maintained similar nutrient availability. Additionally, the finisher 2 diet (1270.1 kg total) was evenly divided into two 317.5 kg allotments; every third feed bag containing 22.7 kg was ground to produce GP. This process was repeated until 544.3 and 190.5 kg of GP were created for the finisher 1 and 2 diet, respectively.

To create the 50, 60 and 70% IP treatments, the calculated amount of 80% IP and GP necessary to achieve the proper FF ratios for each treatment (IP:GP ratios of 50:50, 60:40, and 70:30) were layered in a 26.49 L container and added to the corresponding feeder. The 80% IP treatment was composed entirely of the original diet and was fed without any additional GP.

Experimental Period Broiler Management (d 28 to 49)

Live Performance

Broilers were weighed individually on d 28 by strain and assigned to one of twelve weight classes for each strain (A or B). Twelve birds (1 bird from each weight class for each strain) were weighed and assigned to each floor pen (0.09 m^2/bird); pens contained only Strain A or only Strain B birds (n=12). Each pen was randomly allocated to one of four FF treatments. Feed and water were offered *ad libitum*.

On d 42 and 49, measured variables included average BW, BWG, FI (reported on a per pen basis), and FCR (adjusted for mortality) from d 28 to 42, 42 to 49, and 28 to 49. All animals were reared in compliance with the guidelines set by the Mississippi State University Institutional Animal Care and Use Committee.

Processing Measurements

On both d 42 and 49, four birds per pen (± 100 g avg. BW/pen; 384 birds total) were selected, weighed, tagged, and then cooped. On d 43 and 50, these selected birds were processed at the Mississippi State University Poultry Processing Facility. Hot carcass and abdominal fat pad weights were recorded; carcasses were subsequently chilled in an ice bath for 3 h. Next, debone variables of boneless skinless breast (pectoralis major), tender (pectoralis minor), total breast (pectoralis major and minor), thigh, drumstick, and wing weights were measured. All processing yield data are reported relative to live BW.

Statistical Analysis

A 2 Strain x 4 FF factorial arrangement within a randomized complete block design was utilized. Each treatment was replicated 12 times (12 blocks; designated by location) within the grow-out house. The experimental unit consisted of one floor pen of birds, and the experimental period was from d 28-42 and 28-49. All of the measured variables were analyzed using the GLM procedure in SAS [26]. Treatment mean comparisons were made using Fisher's least significant difference. Significance was set at $P \leq 0.05$.

Results and Discussion

At the beginning of the experimental period, d 28 BW was affected by Strain ($P<0.0001$), as expected based on breed standards [16-17, 27]; however, FF did not influence BW ($P=0.3518$; Table 2.2). Consequently, differences observed in the current study after d 28 may be attributed to changes in FF effects.

Strain Effects

Broiler Performance (d 28 to 42)

Throughout the d 28 to 42 growth period, Strain A exhibited a 12.7% increase in BWG ($P<0.0001$) and an 8.4% increase in BW ($P<0.0001$) when compared to Strain B (Table 2.2). Alternatively, FCR was reduced by 0.18 ($P<0.0001$; Table 2.2). These results were consistent with the specific breed standards [16-17, 27]. Also, both finisher 1 and 2 diets were formulated to meet or exceed the breeder recommendations for both strains (Table 2.1); hence, differences in the main effect Strain are likely due to differing growth rates. No significance was established for Strain on d 28 to 42 FI ($P>0.05$).

Broiler Performance (d 28 to 49)

Results for d 28 to 49 FCR demonstrated that Strain A had an 11 point reduction in FCR ($P<0.0001$) and an 11.4% increase in BWG ($P<0.0001$) when compared to Strain B (Table 2.3). These data are in disagreement with previous research that observed no significant difference in FCR or BWG from d 42 to 53 for 8 different strain-crosses [28]. Differences observed between Strain in the current study are likely due to variations in modern genetics of high-yield and fast-growing birds, whereas previous research used older genotypes [28]. Again, these data are likely attributable to the genetic traits selected for by each primary breeding company [16-17, 27].

Processing (d 43)

Strain A exhibited improved processing weights as compared to Strain B in every category ($P<0.0001$; Table 2.4). Also, d 43 processing yields were different depending on Strain. For instance, Strain A demonstrated a 1.2% increase in d 43 carcass yield when compared to Strain B ($P=0.0003$; Table 2.4). Additionally, Strain A demonstrated a 4-5% increase in breast, tender, and total breast yield when compared to Strain B ($P<0.0001$; Table 2.4). Conversely, drumstick and wing yields were higher in Strain B, exhibiting a percent difference of 4.4 and 4.2%, respectively, as compared to Strain A ($P<0.0001$; Table 2.4).

Processing (d 50)

As for d 43, all d 50 processing weight categories were improved for Strain A birds ($P<0.05$; Table 2.5). Carcass yield was higher in Strain A vs. Strain B (~2.0% difference; $P<0.0001$). Additionally, Strain A demonstrated a 6.0 to 8.0% improvement

in breast, tender, and total breast yield (P<0.05). Similarly, drumstick (P<0.0001) and wing (P=0.0003) yield were higher in Strain B (4.7 and 2.7% difference, respectively) as compared to Strain A birds. Acar and coauthors [29] demonstrated a similar finding, as broilers with significantly higher wing yields also had higher drumstick yields. Overall, broiler strains exhibited improvements in the same processing variables for both d 43 and 50. These data agree with previous literature that suggested acute selection for a trait may cause phenotypic variations within a genotype [30, 31].

Feed Form Effects

Broiler Performance (d 28 to 42)

Data from d 28 to 42 demonstrated that broilers fed 80% IP diets had an 8 point lower FCR (1.68 vs. 1.76) than broilers fed 50% IP diets (P=0.024; Table 2.2). Also, broilers that received 80% IP diets exhibited a higher d 28 to 42 BWG and d 42 BW than broilers fed any other FF treatment (P=0.004 and 0.002, respectively; Table 2.2). The greatest d 28 to 42 BWG and d 42 BW benefit was established when broilers received 80% versus 50% IP treatments, as birds demonstrated a 2.5 (P=0.004) and a 4.7% (P=0.002) increase in BWG and BW, respectively (Table 2.2). These data agree with previous research, as Sellers and cohorts [12] reported similar results in d 28 to 42 BWG and d 42 BW when feeding 75 vs. 55% pellets. In addition, Lemons and others [11] observed a similar increase in d 23 to 38 BWG when birds were fed 70 vs. 40% IP. Although these researchers demonstrated improved BWG when feeding 70 [11] and 75% IP [12], the current data suggests d 28 to 42 BWG can be further improved by 2.3% when feeding 80 vs. 70% IP (P=0.004; Table 2.2). No significance was established for FF on d 28 to 42 FI (P>0.05).

Broiler Performance (d 28 to 49)

Although 80% IP elicited improvements on d 28 to 42 bird performance, it did not translate to improved d 28 to 49 live performance and d 50 processing. It is important to note that data obtained from d 28 to 49 and 42 to 49 may be confounded by changes in stocking density. Stocking density was altered on d 43, four birds per pen were selected for processing, which reduced the bird stocking density of each pen from 0.09 m^2 per bird (d 28 to 42) to 0.14 m^2 per bird (d 42 to 49). Commercial poultry integrator recommended stocking densities for broilers grown in modern solid-walled commercial houses is 0.08 to 0.09 m^2/bird [18, 19]. Previous research concluded that decreasing stocking density from 0.08 to 0.1 m^2/bird will cause 7 week old broilers to consume more feed and have less yield per unit of floor space [32].

Therefore, it is likely that stocking density is correlated to feeder space access. Research has demonstrated that when resources were restricted and stocking density was increased (3.26 and 1.63 vs. 0.82 m^2/bird), broiler aggression and competition for feeder space increased [33]. Furthermore, Lemons and cohorts investigated the effects of FF (40 vs. 70% IP) on increased and industry recommended feeder space access (0.06 m vs. 0.01 m of feeder space per/bird, respectively; stocking density at 0.06 m^2/bird) [11]. This research reported data from the finisher phase that demonstrated that broilers fed a low composition of pellets (40%) with increased feeder space access had similar FI and BWG to broilers fed a high composition of pellets (70%) with increased feeder space access [11]. Perhaps the unexpected lack of differences from d 42 to 49 in the current study were observed due to the change in stocking density on d 43. This in turn increased feeder space (0.07 m/bird from d 28 to 42; 0.11 m/bird from d 42 to 49), creating less

competition at the feeder [33], and more opportunity to preferentially select larger feed particles [34]. Since feed was offered *ad libitum*, it is plausible that broilers had unrestricted access to intact pellets.

Processing (d 43)

Broilers fed 80% IP diets exhibited an advantage in d 43 carcass weight when compared to all 50 and 60% IP diets (P=0.027; Table 2.4). Based upon the linear model constructed by Lilly and coauthors [10], every 10 percentage point increase in FF will result in a 10 g improvement in broiler carcass weight. The current research verifies and suggests further improvement as a 9 (50 vs. 60% IP) and 13 (60 vs. 70% IP) g increase was observed in carcass weight as FF was incrementally increased (P=0.027). Although carcass weights were statistically similar when birds fed 70 vs. 80% IP were compared, data suggests a numerical improvement of 18 g for birds fed 80% IP. Broilers fed 80% IP also exhibited a 2.1-2.7% increase in thigh weight when compared to those fed 50 and 60% IP (P=0.032; Table 2.4). On d 43, fat pad weight was 6% higher in birds fed 80% IP diets compared to broilers that received 50% IP (P=0.026; Table 2.4). Research conducted by Reddy et al. [35] demonstrated that broilers fed pelleted diets had an increased BW and decreased FCR when compared to broilers fed mash or ground pellet diets; these improvements translated into an increased carcass fat percent, which can be directly related to metabolizable energy [36]. Data in the current study support these findings, as broilers fed 80% IP had an increased d 42 BW, reduced FCR, and subsequent increased d 43 fat pad weight when compared to 50% IP diets.

Despite the fact that it was the lowest FF, feeding broilers 50% IP diet resulted in a higher d 43 drumstick yield than any other FF treatment (P=0.023; Table 2.4). Due to

the time and energy associated with the prehension of feed [1-2, 8], perhaps broilers fed a lesser FF (50%) spent more time eating. Consequently, research conducted in a companion study suggests that increased leg weight can be directly associated with longer drinking and shorter resting time [37].

Processing (d 50)

For the main effect of FF, there were no significant differences observed for d 50 processing variables (P>0.05; Table 2.5).

Interactive Effects of Strain and Feed Form

Broiler Performance (d 28 to 42)

Early live performance data (d 28 to 42) demonstrated no live performance interactions (P>0.05).

Broiler Performance (d 28 to 49)

There were no interactions observed between Strain and FF on d 42 to 49 or 28 to 49 FCR, as well as d 42 to 49 or 28 to 49 BWG (P>0.05; Table 2.3). A significant interaction between Strain and FF was demonstrated for d 49 BW (P=0.016; Table 2.3). Strain A birds that were fed diets containing only 60% IP diets exhibited a higher d 49 BW across all other treatments receiving the different FF diets (P=0.016). In addition, Strain A birds, regardless of FF, were heavier on d 49 than Strain B birds; whereas Strain B birds exhibited comparable BW across FF (P=0.016). Also, a trend was noted for an interaction between Strain and FF on d 28 to 49 FCR (P=0.055; Table 2.3). In general, Strain A birds fed 60, 70, and 80% IP exhibited a reduced FCR when compared to Strain A birds fed 50% IP and Strain B birds fed any FF treatment (P=0.055). These data

suggest that Strain A birds were more sensitive in changes to FF on d 49 BW and d 28 to 49 FCR.

Strain and FF interacted for d 28 to 49 FI, whereas Strain A birds consumed on average 1.68 kg per pen more feed from d 28 to 49 than Strain B birds (P=0.012). Additionally, Strain A broilers fed 60% IP diets consumed more feed as compared to other strain and FF treatment combinations, with the exception of Strain A birds fed 50% IP diets. However, the interactions between Strain and FF on d 49 BW and d 28 to 49 FCR demonstrated that regardless of FF, Strain A weighed more and converted feed better than Strain B, justifying the increased d 28 to 49 FI.

Processing (d 43)

No interactions were established for any d 43 processing weights (P>0.05). Strain and FF interactively affected both d 43 breast yield (P=0.043) and total breast yield (P=0.025; Table 2.4). Strain A birds fed 50, 60, and 70% IP diets exhibited higher breast and total breast yield than Strain B birds fed the same FF treatments. Strains A and B fed 80% IP demonstrated similar breast and total breast yields. Literature has documented differences on carcass traits for differing strains [28, 29]; however, to our knowledge, there is little to no peer-reviewed data that investigates the interactive effects of Strain and FF. Hence, it is possible that Strain A is less sensitive to 80% IP and more sensitive to 50, 60, or 70% IP when breast and total breast yields are observed, whereas Strain B is more sensitive to 80% IP. However, observed differences may also be due to the differences in the traits genetically selected for each strain (i.e. fast-growing or high-yield).

Processing (d 50)

A significant Strain x FF interaction was established for d 50 tender weight (P=0.007; Table 2.5). Regardless of FF, Strain A broilers demonstrated on average a 15.5% increase in d 50 tender weight compared to Strain B broilers (P=0.007; Table 2.5). Strain A birds fed 60% IP diets had a 4.5, 6, and 9% increase in d 50 tender weight as when compared to Strain A birds fed 50, 70, and 80% IP treatments (P=0.007; Table 2.5); whereas Strain B birds had similar d 50 tender weights across all FF treatments (P=0.007; Table 2.5), indicating that Strain B birds were less sensitive to FF on tender weight. There were no further significant interactions between Strain and FF on d 50 processing weight variables (P>0.05; Table 2.5). Additionally, no other interactions were established for Strain and FF on d 50 processing yield variables (P>0.05; Table 2.5). These data disagree with previous research that found differences between 8 different broiler strains on d 53 processing weights and yield [29]. Data in the current study suggest that d 50 processing may not be affected by FF beyond tender weight.

Overall Summary

Data in the current study demonstrates that feeding more pellets (80%) can be beneficial to the d 28 to 42 live performance variables of BW, BWG, and FCR (P=0.002, 0.004, and 0.024, respectively; Table 2.2). Although 80% IP demonstrated the greatest d 28 to 42 performance benefits, this FF may not always be attainable by a commercial mill. Also, depending on the integrator's metric, it may not be of importance to strive for 70 over 60% IP as d 28 to 42 data demonstrated similarities between the two FF for BW, BWG, and FCR (Table 2.2). However, previous FF research utilizing one broiler strain has suggested otherwise, as feeding more pellets has been demonstrated to improve

broiler performance [10-12]. Processing results suggest that if 80% IP can be achieved, each strain of broiler will exhibit similar d 43 breast and total breast yield. However, if a commercial mill is manufacturing 70% IP or less, these data show that the strain of broiler should be taken into consideration due to the interaction each has with FF on d 43 breast and total breast yield (P=0.043 and P=0.025, respectively; Table 2.4).

The benefits associated with feeding pelleted rations demonstrated in d 28 to 42 data of the current study are supported by previous literature [1-8]. The current research investigated the benefits associated with incremental improvements in FF, although the effects of nutrient segregation were not considered.

Pelleting is a complex process, and many feed manufacturing variables such as steam-conditioning time and temperature, pressure, production rate, moisture addition, and diet formulation can affect pellet quality [3-7, 38-40]. As a result, changes in pellet quality may affect the rate of nutrient segregation [2, 41]. Should the effects of nutrient segregation be explored, the benefits of feeding diets with high pellet compositions would presumably intensify [10]. Previous research determined that nutrient segregation occurred throughout transportation and augering for both 55 and 75% pellet diets [41]; however, a clear benefit in BWG and FCR was observed when a higher FF (75% pellets) was fed to heavy broilers (d 28 to 56) [41].

Although previous research and the current study have established that feeding diets with increasing FF can improve d 21 to 42 performance [10, 11], more research is warranted on d 42+ old birds. Therefore, future research should also investigate the effects and variations of FF on modern broiler strains over a longer grow-out period. The experimental design should take into consideration stocking density and feeder space

access in order to obtain accurate results for later growth phases of different modern commercial broilers fed diets varying in FF.

Conclusions and Applications

1. Data suggests that strain may be an important consideration from d 28 to 42 when deciding on pellet quality; however, d 28 to 49 data is less clear.

2. More research is necessary on broilers raised to 42+ d. Data from the current study may be confounded due to a decrease stocking density from d 28 to 49 (0.09 to 0.14 m^2/bird), which allowed more feeder space per bird, less competition at the feeder, and more opportunity to favorably select feed due to *ad libitum* consumption.

3. Regardless of strain, broilers fed diets with 80% IP demonstrated improvements in d 42 BW and 28 to 42 BWG when compared to any other FF treatment. Feeding broilers 80% IP vs. 50% IP increased d 42 BW and d 28 to 42 BWG by 2.47% and 4.17%, respectively, whereas d 28 to 42 FCR was reduced by 8 points.

Table 2.1 Ingredient inclusion and calculated nutrient composition of finisher 1 and finisher 2 experimental diets[1]

	Finisher 1 diet (28 to 42 d)	Finisher 2 diet (42 to 49 d)
Ingredient, %		
Corn	58.46	58.23
Soybean meal (48% CP)	25.00	23.19
Corn DDGS[2]	7.000	9.000
Meat and bone meal[3]	3.500	3.250
Animal/vegetable blend fat[4]	3.068	3.653
Calcium carbonate	1.245	1.203
Dicalcium phosphate	0.420	0.276
Sodium bicarbonate	0.300	0.300
Vitamin/mineral premix[5]	0.275	0.250
DL-Methionine	0.222	0.203
Salt	0.175	0.170
L-Lysine HCL	0.147	0.138
BMD 50[6]	0.050	0.050
L-Threonine	0.046	0.024
Choline chloride	0.042	0.023
Phytase enzyme[7]	0.020	0.020
Selenium 0.02%	0.017	0.017
Xylanase enzyme[8]	0.010	0.010
Calculated nutrients		
ME, kcal/kg	3179.73	3223.17
CP, %	20.55	19.96
Available Phosphorus, %	0.410	0.370
Total TSAA, %	0.884	0.854
Total Methionine, %	0.537	0.514
Total Lysine, %	1.150	1.098
Total Threonine, %	0.812	0.768
Calcium, %	0.943	0.870
Sodium, %	0.200	0.190

[1]Diets formulated to meet or exceed breeder growth recommendations for each strain; finisher 1 averaged 83% pellets and finisher 2 average 84.5% pellets

[2]Distillers dried grains with solubles.

[3]H. J. Baker and Bro., Little Rock, AR

[4]Animal-vegetable oil blend

[5]Provided per kilogram of diet: 0.02% manganese; 0.02% zinc; 0.01% iron; 0.0025% copper; 0.0003% iodine; 0.00003% selenium; 0.69 mg of folic acid; 386 mg of choline; 6.61 mg of riboflavin; 0.03 mg of biotin; 1.38 mg of vitamin B6; 27.56 mg of niacin; 6.61 mg of pantothenic acid; 2.20 mg of thiamine; 0.83 mg of menadione; 0.01 mg of vitamin B12; 16.53 IU of vitamin E; 2,133 ICU of vitamin D3; and 7,716 IU of vitamin A

[6]Active drug ingredient bacitracin methylene disalicylate, 50 g/lb inclusion; Zoetis, Florham Park, NJ

[7]Heat stable liquid phytase; DSM Nutritional Products Inc., Parsippany, NJ

[8]AB Vista Feed Ingredients, Marlborough, UK

Table 2.2 Live growth performance from d 28 to 42 of each male broiler strain fed diets varying in feed form

Strain[1]	FF[2]	D28 BW (kg)	D28-42 FCR	D42 Avg BW (kg)	D28-42 Avg BWG[3] (kg)	D28-42 Avg FI/pen[4] (kg)
Strain A	**50:50**	1.51	1.68	3.082	1.597	31.55
	60:40	1.51	1.66	3.143	1.635	31.77
	70:30	1.50	1.61	3.128	1.626	30.80
	80:20	1.50	1.57	3.161	1.658	31.23
Strain B	**50:50**	1.44	1.83	2.854	1.414	31.08
	60:40	1.44	1.80	2.865	1.423	30.61
	70:30	1.44	1.82	2.872	1.435	31.25
	80:20	1.44	1.79	2.916	1.476	31.39
SEM		0.0044	0.0249	0.0172	0.0162	0.3539
Marginal means						
Strain A	-	1.51[a]	1.63[b]	3.130[a]	1.631[a]	31.33
Strain B		1.44[b]	1.81[a]	2.877[b]	1.437[b]	31.09
SEM		0.0022	0.0125	0.0086	0.0081	0.1770
-	**50:50**	1.47	1.76[a]	2.964[c]	1.503[b]	31.34
	60:40	1.48	1.73[ab]	3.004[b]	1.529[b]	31.14
	70:30	1.47	1.71[ab]	2.999[b]	1.531[b]	31.03
	80:20	1.47	1.68[b]	3.038[a]	1.567[a]	31.34
SEM		0.0031	0.0176	0.0126	0.0115	0.2503
Main effect and interaction probabilities						
Strain		<0.0001	<0.0001	<0.0001	<0.0001	0.3135
FF		0.3518	0.0237	0.0018	0.0042	0.8347
Strain x FF		0.8543	0.3195	0.5362	0.7566	0.1205

[a-e]Means within a column not sharing a common superscript differ ($P \leq 0.05$)

[1]Two modern strains of commercial broilers

[2]FF = Feed form; common diets were manufactured to contain 80% intact pellets (IP). A portion of the 80% IP diet was ground via roller mill to create ground pellets (GP). GP were added to the 80% IP diets to create IP:GP ratios of 50:50, 60:40, and 70:30. The 80:20 IP:GP treatment was composed entirely of the original diet and contained no additional GP

[3]BWG = body weight gain

[4]FI = feed intake; FI is presented on a per pen basis

Table 2.3 Live growth performance from d 28 to 49 of each male broiler strain fed diets varying in feed form

Strain[1]	FF[2]	D42-49 FCR	D49 Avg BW (kg)	D42-49 Avg BWG (kg)	D28-49 FCR	D28-49 Avg BWG (kg)	D28-49 Avg FI/pen[4] (kg)
Strain A	**50:50**	2.82	3.646^{b}	0.559	1.88	2.981	43.57^{ab}
	60:40	2.58	3.839^{a}	0.652	1.84	3.190	44.77^{a}
	70:30	2.62	3.718^{b}	0.584	1.80	3.033	43.12^{bc}
	80:20	2.91	3.712^{b}	0.534	1.80	3.048	43.35^{bc}
Strain B	**50:50**	2.38	3.430^{c}	0.588	1.95	2.710	42.17^{cde}
	60:40	2.30	3.442^{c}	0.590	1.90	2.750	41.33^{e}
	70:30	2.43	3.411^{c}	0.548	1.94	2.701	41.79^{de}
	80:20	2.66	3.448^{c}	0.534	1.95	2.773	42.79^{bcd}
SEM		0.0814	0.0283	0.0203	0.0206	0.0439	0.4412
Marginal means							
Strain A	-	2.73^{a}	3.731	0.583	1.83^{b}	3.065^{a}	43.72
Strain B	-	2.44^{b}	3.433	0.565	1.94^{a}	2.733^{b}	42.02
SEM		0.0407	0.0142	0.0101	0.0103	0.0220	0.2206
-	**50:50**	2.60^{b}	3.533	0.574^{b}	1.92	2.839^{b}	42.87
	60:40	2.44^{b}	3.641	0.621^{a}	1.87	2.969^{a}	43.05
	70:30	2.52^{b}	3.564	0.566^{b}	1.87	2.867^{b}	42.45
	80:20	2.78^{a}	3.580	0.534^{b}	1.87	2.910^{ab}	43.07
SEM		0.0576	0.0201	0.0143	0.0146	0.0310	0.3120
Main effect and interaction probabilities							
Strain		<0.0001	<0.0001	0.2319	<0.0001	<0.0001	<0.0001
FF		0.0006	0.0044	0.0007	*0.0842*	0.0310	0.4715
Strain x FF		0.4751	0.0159	0.1350	*0.0554*	0.1960	0.0117

[a-e]Means within a column not sharing a common superscript differ ($P \leq 0.05$)

[1]Two modern strains of commercial broilers

[2]FF = Feed form; common diets were manufactured to contain 80% intact pellets (IP). A portion of the 80% IP diet was ground via roller mill to create ground pellets (GP). GP were added to the 80% IP diets to create IP:GP ratios of 50:50, 60:40, and 70:30. The 80:20 IP:GP treatment was composed entirely of the original diet and contained no additional GP

[3]BWG = body weight gain

[4]FI = feed intake; FI is presented on a per pen basis

Table 2.4 D 43 processing weight and yields (relative to d 42 live BW) of two different male broiler strains fed diets varying in feed form

Strain[1]	FF[2]	Weight (kg)								Yield (%)							
		Carcass	Total Breast[3]	Breast[4]	Tender[5]	Drum	Thigh	Wing	Fat Pad[6]	Carcass	Total Breast	Breast	Tender	Drum	Thigh	Wing	Fat Pad
Strain A	50:50	2.173	0.691	0.563	0.127	0.281	0.349	0.236	0.032	70.72	22.46^{a}	18.37^{a}	4.09	9.16	11.30	7.67	0.99
	60:40	2.182	0.689	0.572	0.118	0.281	0.349	0.236	0.036	70.56	22.28^{ab}	18.42^{a}	3.86	9.05	11.26	7.69	1.14
	70:30	2.214	0.689	0.572	0.118	0.281	0.354	0.240	0.036	71.08	22.11^{abc}	18.30^{a}	3.81	8.98	11.37	7.72	1.10
	80:20	2.223	0.686	0.563	0.123	0.286	0.358	0.240	0.036	70.51	21.75^{bcd}	17.87^{ab}	3.88	9.13	11.37	7.57	1.09
Strain B	50:50	2.015	0.601	0.499	0.100	0.281	0.327	0.231	0.027	69.93	20.89^{e}	17.37^{b}	3.52	9.73	11.33	8.03	0.88
	60:40	2.024	0.609	0.508	0.104	0.272	0.322	0.231	0.027	70.10	21.13^{de}	17.56^{b}	3.57	9.42	11.21	8.03	0.97
	70:30	2.015	0.601	0.504	0.100	0.272	0.322	0.231	0.023	69.68	20.78^{e}	17.35^{b}	3.43	9.42	11.18	7.97	0.84
	80:20	2.046	0.633	0.526	0.104	0.272	0.331	0.231	0.027	69.85	21.58^{cd}	17.95^{ab}	3.63	9.33	11.29	7.92	0.90
SEM		0.0138	0.0081	0.0070	0.0027	0.0026	0.0032	0.0018	0.0012	0.3055	0.2408	0.2139	0.0857	0.0854	0.0940	0.0532	0.0404
Marginal means																	
Strain A	-	2.201^{a}	0.689^{a}	0.567^{a}	0.123^{a}	0.281^{a}	0.354^{a}	0.236^{a}	0.032^{a}	70.71^{a}	22.14	18.24	3.91^{a}	9.07^{b}	11.33	7.66^{b}	1.08^{a}
Strain B		2.024^{b}	0.611^{b}	0.508^{b}	0.104^{b}	0.272^{b}	0.327^{b}	0.231^{b}	0.027^{b}	69.89^{b}	21.09	17.56	3.54^{b}	9.48^{a}	11.25	7.99^{a}	0.90^{b}
SEM		0.0069	0.0040	0.0035	0.0013	0.0013	0.0016	0.0009	0.0006	0.1527	0.1204	0.1070	0.0428	0.0427	0.0470	0.0266	0.0202
-	50:50	2.092^{b}	0.644	0.531	0.113^{ab}	0.281	0.337^{b}	0.231	0.028^{b}	70.29	21.64	17.85	3.79	9.45^{a}	11.32	7.85	0.93^{b}
	60:40	2.101^{b}	0.649	0.540	0.111^{ab}	0.277	0.335^{b}	0.236	0.031^{a}	70.33	21.70	17.99	3.71	9.24^{b}	11.23	7.86	1.06^{a}
	70:30	2.114^{ab}	0.645	0.535	0.109^{b}	0.277	0.339^{ab}	0.236	0.029^{ab}	70.38	21.44	17.82	3.62	9.20^{b}	11.27	7.84	0.97^{b}
	80:20	2.132^{a}	0.659	0.544	0.114^{a}	0.281	0.344^{a}	0.236	0.030^{a}	70.18	21.67	17.91	3.76	9.23^{b}	11.33	7.75	1.00^{ab}
SEM		0.0098	0.0057	0.0049	0.0019	0.0019	0.0023	0.0013	0.0009	0.2160	0.1703	0.1513	0.0606	0.0603	0.0665	0.0376	0.0285
Main effect and interaction probabilities																	
Strain		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003	<0.0001	<0.0001	<0.0001	<0.0001	0.2979	<0.0001	<0.0001
FF		0.0270	0.2879	0.3641	0.1679	0.0997	0.0323	0.6709	0.0260	0.9249	0.6841	0.8853	0.1806	0.0233	0.7085	0.1267	0.0288
Strain x FF		0.4246	0.0885	0.0991	0.3332	0.1359	0.4913	0.4739	0.3188	0.4515	0.0250	0.0426	0.2392	0.1897	0.7298	0.7513	0.3579

[a-e]Means within a column not sharing a common superscript differ ($P \leq 0.05$)

[1]Two modern strains of commercial broilers

[2]FF = Feed form; common diets were manufactured to contain 80% intact pellets (IP). A portion of the 80% IP diet was ground via roller mill to create ground pellets (GP). GP were added to the 80% IP diets to create IP:GP ratios of 50:50, 60:40, and 70:30. The 80:20 IP:GP treatment was composed entirely of the original diet and contained no additional GP

[3]Total Breast = pectoralis major plus pectoralis minor

[4]Breast = pectoralis major

[5]Tender = pectoralis minor

[6]Fat pad = abdominal fat pad

Table 2.5 D 50 processing weights and yields (relative to d 49 live BW) of two different male broiler strains fed diets varying in feed form

Strain[1]	FF[2]	Weight (kg)								Yield (%)							
		Carcass	Total Breast[3]	Breast[4]	Tender[5]	Drum	Thigh	Wing	Fat Pad[6]	Carcass	Total Breast	Breast	Tender	Drum	Thigh	Wing	Fat Pad
Strain A	50:50	2.668	0.869	0.712	0.158^{ab}	0.341	0.432	0.283	0.041	72.57	23.66	19.35	4.31	9.29	11.76	7.70	1.12
	60:40	2.777	0.898	0.735	0.165^{a}	0.348	0.444	0.295	0.045	72.05	23.30	19.03	4.27	9.02	11.52	7.65	1.17
	70:30	2.686	0.889	0.735	0.155^{b}	0.338	0.434	0.287	0.042	72.81	24.08	19.89	4.19	9.15	11.74	7.76	1.14
	80:20	2.691	0.869	0.717	0.151^{b}	0.343	0.431	0.292	0.044	72.77	23.50	19.41	4.09	9.28	11.64	7.91	1.18
Strain B	50:50	2.455	0.760	0.626	0.133^{c}	0.330	0.401	0.274	0.034	70.60	21.85	18.01	3.84	9.51	11.54	7.89	0.99
	60:40	2.459	0.756	0.622	0.133^{c}	0.333	0.407	0.276	0.034	71.25	21.90	18.05	3.86	9.65	11.79	7.99	1.00
	70:30	2.505	0.784	0.644	0.138^{c}	0.341	0.404	0.280	0.035	71.28	22.33	18.40	3.93	9.70	11.51	7.98	1.00
	80:20	2.464	0.775	0.640	0.136^{c}	0.333	0.399	0.277	0.034	71.28	22.43	18.48	3.94	9.63	11.53	8.02	0.99
SEM		0.0292	0.0134	0.0121	0.0026	0.0044	0.0066	0.0028	0.0023	0.2888	0.2611	0.2440	0.0648	0.0816	0.1481	0.0806	0.0583
Marginal means																	
Strain A	-	2.704^{a}	0.881^{a}	0.726^{a}	0.157	0.342^{a}	0.435^{a}	0.289^{a}	0.043^{a}	72.56^{a}	23.65^{a}	19.43^{a}	4.22^{a}	9.18^{b}	11.66	7.76^{b}	1.15^{a}
Strain B		2.468^{b}	0.769^{b}	0.635^{b}	0.135	0.334^{b}	0.402^{b}	0.276^{b}	0.034^{b}	71.10^{b}	22.13^{b}	18.23^{b}	3.89^{b}	9.62^{a}	11.59	7.97^{a}	1.00^{b}
SEM		0.0146	0.0067	0.0061	0.0013	0.0022	0.0033	0.0014	0.0011	0.1444	0.1306	0.1220	0.0324	0.0408	0.0741	0.0403	0.0291
-	50:50	2.554	0.812	0.667	0.146	0.335	0.415	0.278	0.038	71.56	22.74	18.66	4.07	9.40	11.64	7.80	1.05
	60:40	2.618	0.827	0.676	0.149	0.340	0.425	0.285	0.040	71.65	22.60	18.54	4.06	9.34	11.66	7.83	1.08
	70:30	2.595	0.837	0.690	0.146	0.339	0.419	0.283	0.039	72.04	23.20	19.14	4.06	9.42	11.63	7.87	1.07
	80:20	2.577	0.822	0.681	0.144	0.338	0.415	0.285	0.040	72.02	22.96	18.95	4.02	9.45	11.59	7.96	1.09
SEM		0.0207	0.0095	0.0086	0.0018	0.0031	0.0047	0.0019	0.0016	0.2042	0.1847	0.1726	0.0458	0.0577	0.1047	0.0570	0.0412
Main effect and interaction probabilities																	
Strain		<0.0001	<0.0001	<0.0001	<0.0001	0.0116	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.4889	0.0003	0.0004
FF		0.2557	0.4279	0.3741	0.2700	0.7635	0.4018	0.0611	0.8660	0.2556	0.1210	0.0693	0.8000	0.5269	0.9689	0.1762	0.9536
Strain x FF		0.1286	0.3249	0.5899	0.0065	0.2321	0.9294	0.1134	0.7835	0.2517	0.4626	0.5938	0.0551	0.0596	0.2926	0.5421	0.9567

[a-e]Means within a column not sharing a common superscript differ ($P \leq 0.05$)

[1]Two modern strains of commercial broilers

[2]FF = Feed form; common diets were manufactured to contain 80% intact pellets (IP). A portion of the 80% IP diet was ground via roller mill to create ground pellets (GP). GP were added to the 80% IP diets to create IP:GP ratios of 50:50, 60:40, and 70:30. The 80:20 IP:GP treatment was composed entirely of the original diet and contained no additional GP

[3]Total Breast = pectoralis major plus pectoralis minor

[4]Breast = pectoralis major

[5]Tender = pectoralis minor

[6]Fat pad = abdominal fat pad

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CHAPTER III

FEED FORM AND LIQUID APPLICATION METHOD EFFECTS ON FEED AUGERING SEGREGATION AND SUBSEQUENT BROILER PERFORMANCE

Summary

General benefits of feeding pellets to poultry are documented; however, replicated research has not yet identified the impact of augering feed throughout a commercial feed line on pellet quality, feed segregation, and resulting bird performance. Two experiments were conducted in the current study. The objective of experiment 1 was to determine the effects of pellet to fine ratio (PF) and liquid application method during feed manufacture (LAM; mixer or post-pellet addition of fat and liquid phytase) on physical and nutrient segregation post augering throughout a commercial poultry feed line. Samples for each of the augered diets were obtained at 0, 15, 30, 32, 44, and 58 m on the feed line. Post augering, each diet was retained and separated by location from 0 to 30 and 32 to 58 m for experiment 2. The objective experiment 2 was to determine the effects of physical segregation, nutrient segregation, and augering location (0-30 or 32-58 m) on d 28 to 56 performance and d 57 processing characteristics. In experiment 1, augering post-pellet LAM (PPLAM) diets increased percent pellets compared to mixer LAM (MLAM). A Location x PF interaction established that percent pellets decreased when augered from 0 to 15 and 44 to 58 m. Augering from 15 to 44 m demonstrated no change in percent

pellets for 55:45 PF diets; however, 75:25 PF diets fluctuated. In experiment 2, a LAM x PF x Location interaction demonstrated a decrease in d 28 to 42 BW gain (BWG) for birds fed MLAM and 75:25 PF diets as feed was augered across Location when compared to PPLAM and 75:25 PF diets. Also, a LAM x PF x Location interaction demonstrated that PPLAM diets affected d 56 BW uniformity by the distance feed traveled within a broiler house. The main effect of PF demonstrated that 75:25 diets improved overall BWG, carcass weight, and total breast weight.
Keywords: pellet quality, nutrient segregation, feed manufacture, broiler performance

Description of Problem

Modern commercial broilers are fed predominately pelleted diets, and the general benefits of feeding pellets are well documented in previous literature [1-5]. Moreover, these performance benefits can become considerably greater as improvements in pellet quality are made [6-10]. It is likely that nutrient segregation decreases with improved pellet quality; however, this is not widely documented in literature. In addition, the effect of feed augering on pellet quality has not been extensively investigated, nor have the benefits of feed quality on heavy broilers (>42 d of age). Pellet quality can be influenced by a number of factors [12-15], and improvements require an investment; should feed augering decrease pellet quality and increase nutrient segregation, feed manufacturers may better appreciate costs and potential benefits.

Data observed in small field trials suggested that nutrient segregation occurred during feed augering [4, 11]. In a field study conducted by Mississippi State and West Virginia Universities, the most notable nutrient segregation was observed in analyzed phytase activity; especially for diets manufactured with post-pellet liquid application

method (PPLAM) [11]. Liquid application method (LAM) refers to the manner in which supplemental fat and other liquids, such as phytase, are added to the diet. For mixer LAM (MLAM), all of liquids are added in the mixer, whereas PPLAM requires no or low mixer-added fat, with the majority of supplemental fat and liquids added after pelleting. Due to concerns over PPLAM amplifying the rate in which nutrients, such as phytase, segregate [11], as well as adversely affecting nutrient availability [16], there is a need to investigate if this nutrient segregation is significant enough to elicit an effect on broiler performance.

While previous field data obtained from several farms in various parts of the Southeast United States determined that feed quality was affected by feed augering based on manufacturing technique, the results only represented a snapshot in time [11]. Therefore, two experiments were conducted in the current study to further explore the effects of feed manufacture and augering on physical segregation, nutrient segregation, and subsequent broiler performance. The objective of experiment 1 was to create practical diets that varied in pellet to fine ratio (PF; 75:25 or 55:45) and LAM (mixer or post-pellet), and auger these diets through a feed line in a commercial broiler house to determine the effects of feed augering on physical and nutrient segregation (using phytase as a marker) over time and location. The objective of experiment 2 was to feed the augered diets from experiment 1 that varied in PF, LAM, and location (0-30 or 32-58 m on the feed line) to determine if changes in physical and nutrient segregation were enough to elicit d 28 to 56 broiler performance and processing differences.

Materials and Methods

Experiment 1

Diet Preparations

All experimental diets were manufactured at West Virginia University [21]. One nutritionally common diet was formulated according to Ross x Ross 708 broiler recommendations [22] (Table 3.1), and contained corn, soybean meal, distiller's dried grains with solubles, and meat and bone meal. Master batches were mixed in a 0.907-tonne vertical screw mixer [23] for 10 minutes dry and 10 minutes post liquid addition, and 1.00% of the supplemental fat inclusion (total inclusion of 2.44%) was added in the mixer to help with nutrient retention during pelleting [16-18]. Also, phytase was excluded from the master batches. The remaining iquid additions of supplemental fat and all of the phytase were added to the diets either prior to (MLAM) or after (PPLAM) pelleting, depending on the manufacturing technique utilized. Each batch was equally distributed and assigned to 1 of 4 treatments.

The liquid phytase utilized was included in the diets at a target dose of 2000 FTU/kg per the manufacturer's recommendations; calcium and available phosphorus were adjusted to account for the phytase inclusion (Table 3.1). Treatments manufactured using MLAM were remixed with the remaining 1.44% supplemental fat, as well as a heat-stable liquid phytase (0.005% inclusion), for 15 minutes prior to pelleting. To ensure proper mixing between the master batches, treatments manufactured using PPLAM were also mixed for 15 minutes and subsequently pelleted. For PPLAM diets, the remaining 1.44% supplemental fat and 0.005% phytase inclusions were added after pelleting by conveying the pelleted diet back into the mixer and adding the appropriate

volume of liquid fat and phytase through a micro ingredient chute on the mixer [16]. Based on the field research previously demonstrating that phytase segregated the most out of all the analyzed ingredients [11], phytase was chosen again to identify the level of segregation occurring during feed augering. Unconditioned mash samples were taken for the MLAM diets before they were conditioned. Analyzed phytase activity in the unconditioned mash of the MLAM diets was 2050 FTU/kg [24].

Each diet was initially manufactured to contain 75:25 PF by conditioning mash for 10 s at 78 ± 2°C [16, 17] then extruding the conditioned mash through a 4.76 x 38.1 mm pellet die at an average production rate of 0.816 tonne/h [8, 13]. A portion of each diet was subsequently ground via hammer mill in order to create fines. The manufactured fines were then added back to a portion of the original 75:25 PF diets and mixed for 2 minutes and 30 seconds in order to create 55:45 PF diets; thereby creating four experimental diets varying in LAM and PF.

Descriptive feed manufacture data for percent pellets [25], pellet durability index (PDI) [26], modified pellet durability index (MPDI) [26], and surviving pellets percentage [27] were obtained for each of the four experimental diets (Table 3.2).

Feed Augering Sampling Procedure

Using a randomized complete block design, one of the four treatments was augered into a feed bin (11,000 kg capacity) [28] at one of Mississippi State University's commercial poultry houses (122 m x 16 m) using a 12.8 m auger (20.32 cm diameter) [29] to simulate feed truck augering. It should be noted that no birds were in the house during the experimental period. Next, the experimental unit (680.6 kg) was augered into the commercial feed line system that measured 58 m long [30]. Sampling locations were

designated at 0, 15, 30, 32, 44 and 58 m along the feed line. The middle point of the feed line was determined to be at 31 m, which is the point where the migration fence separated the feed line. Once the feed line was completely filled, samples were taken from feed pan locations of 30 and 58 m. The feed line auger was then emptied from 0 to 30 and 32 to 58 m to clear the feed line and retain feed according to treatment and location for the subsequent feeding trial (experiment 2; Table 3.3). The remaining samples were taken from the feed pan locations of 0, 15, 32, and 44 m. In addition, every feed pan between these sampling locations was then emptied and collected according to treatment and location for the subsequent feeding trial (experiment 2; Table 3.3). Sampling process was completed four times for each treatment (4 replicates/treatment; Figure 3.1).

This resulted in a total of 384 samples which were analyzed for the measured variables of percent pellets [25] and pellet durability (in terms of surviving pellets [27]) at each sampling pan. Percent pellets were determined by sifting samples using a No. 6 American Society for Testing and Materials screen [25]. Sifted pellet samples were analyzed for surviving pellets using a New Holmen Pellet Tester [27]. A portion of the sifted pellets and fines were sent to a commercial feed lab [31] for phytase activity analysis using the standard AOAC 2000.12 procedure [24]. Analyzed phytase activity in each sample was reported relative to the phytase activity in the unconditioned mash samples (2050 ftu/kg).

Statistical Analysis

For experiment 1, a 2 PF (75:25 or 55:45) x 2 LAM (mixer or post-pellet LAM) factorial arrangement was used, with the experimental unit of 680.6 kg that was augered as a randomized complete block with a split-split plot design. Treatments were blocked

by run order and each treatment was replicated four times (1 replication/day). The split plot unit was augering time (each time the feed line was completely filled), and there were four augering times per run. The split-split plot unit was feed pan location (0, 15, 30, 32, 44, and 58 m). Data were analyzed using the GLM procedure in SAS [32]. Multiple treatment mean comparisons were made using Fisher's least significant difference and significance was established at $P \leq 0.05$.

Experiment 2

Pretest Period Broiler Management (d 0 to 28)

On day of age, Ross x Ross 708 broilers were obtained from a commercial hatchery [33] and feather-sexed upon arrival to the Mississippi State University Poultry Research Unit. A total of 1536 male broilers were placed in floor pens (0.91 x 1.22 m; 16 birds/pen; 0.07 m^2/bird) of a solid-walled, cross-ventilated grow-out house. The house was heated via forced air and cooled via evaporative cool cells. Each pen contained a hanging feeder (16.0 kg capacity) and nipple drinkers (3 nipples/pen) for *ad libitum* feed and water consumption.

Birds received a common starter diet in the form of crumbles from d 0 to 14 and a common grower diet in the form of pellets from d 15 to 28. These diets were formulated to meet or exceed Ross x Ross 708 male broiler recommendations [22] and were comprised of corn, soybean meal, distiller's dried grains with solubles, and meat and bone meal. Both the starter and grower diets were manufactured at the Mississippi State University Poultry Research Unit, with starter fed as crumbles and grower as pellets.

Ross x Ross 708 breeder recommendations for temperature and lighting programs were utilized during the grow-out period [34]. On day of age, the ambient house

temperature was 32.7°C; house temperature was incrementally reduced weekly until 16.1°C was reached on d 49. The lighting program provided birds with 24 h of light from d 0 to 7. Beginning at d 7, birds received 20 h of light and 4 h of dark throughout the remainder of the grow-out period. On d 0, lighting intensity was 26.9 lux. Starting at d 10, lighting intensity was decreased until 2.7 lux was achieved on d 21; from d 21 to 56, lighting intensity remained at 2.7 lux.

Experimental Period Broiler Management (d 28 to 56)

For the live performance trial conducted in experiment 2, the previously augered diets from experiment 1 were used. These diets were originally manufactured to vary in PF (75:25 or 55:25) and LAM (mixer or post-pellet). As they were augered and collected separately from 0-30 and 32-58 m in experiment 1, the treatment outline expanded to a 2 PF x 2 LAM x 2 Location factorial arrangement (Table 3.3). The migration fence separated the feed line at 31 m, which would have confined birds to either side had they been in the house; ergo, Locations of 0-30 m and 32-58 m were chosen.

The current study's experiment 2 period began on d 28. On this day, all of the birds were individually weighed and placed in one of twelve weight classes. One bird from each weight class was assigned to each pen (12 birds/pen; 0.09 m^2/bird; 96 pens), and each pen was randomly allotted one of the eight experimental finisher diets (Table 3.3) manufactured in experiment 1 that varied in PF, LAM, and Location. Broilers were able to consume feed and water *ad libitum*.

Pen and feeder weights were recorded on d 42, 49, and 56 to measure performance variables of BW, BW gain (BWG), and FCR (adjusted for mortality). On d 56, birds were weighed individually to measure BW uniformity (CV). Mortality was not

significant in the current study; therefore, those data will not be presented. All broilers were cared for in accordance with the standards required by the Mississippi State University Institutional Animal Care and Use Committee.

Processing Measurements (d 57)

On d 56, a total of 384 broilers (4 birds/pen ± 100 g avg. BW/pen) were chosen, weighed, tagged, and then cooped for d 57 processing at the Mississippi State University Poultry Processing Facility. Hot carcass and abdominal fat pad weights were measured, then carcasses were chilled in an ice bath for 3 h. Next, debone variables of boneless skinless breast, tender, thigh, drumstick, and wing weights were recorded. Processing yields are reported as debone traits relative to d 56 live BW.

Statistical Analysis

In experiment 2, a 2 PF (75:25 or 55:45) x 2 LAM (mixer or post pellet LAM) x 2 Location (0-30 or 32-58 m) factorial arrangement was used as a randomized complete block design. The experimental unit was one floor pen and each treatment was equally and randomly assigned to a pen within the same location (12 blocks/replication). The experimental period was d 28 to 56. Data were analyzed via the GLM procedure in SAS [32], and multiple treatment mean comparisons were made using Fisher's least significant difference. Data were considered significant at $P \leq 0.05$.

Results and Discussion

Experiment 1: Feed Augering

Liquid Application Method Effects

In general, diets manufactured utilizing PPLAM had a 6 percentage point increase pellets across location when compared to MLAM (P<0.0001; Table 3.4). Previous research has demonstrated that higher levels of mixer-added fat (2.18-4.00 vs. 1.00%) can be detrimental to pellet quality [16-18], and differences observed in the current study for percent pellets are likely attributable to the manner in which fat was added to the diet. Since fat coats feed particles [19] and lubricates the pellet die [20], PPLAM diets had 1.00% of the fat inclusion added in the mixer and a lower conditioning temperature (78 ± 2°C) to ensure that broiler performance in experiment 2 was not affected by nutritional value associated with amino acid denaturation or enzyme loss [16-18]. Diets manufactured with MLAM had all of the 2.44% fat inclusion added in the mixer, while PPLAM treatments only received 1.00% mixer-added fat, with the remaining fat added post-pellet (1.44%).

Interactive Effects of Pellet to Fine Ratio and Liquid Application Method across Location and Time

As diets were augered throughout the feed line, a significant PF x location interaction demonstrated a rapid decrease in percent pellets for both PF from 0 to 15 and 44 to 58 m (P<0.0001; Figure 3.2). Diets containing 55:45 PF demonstrated no change in percent pellets when augered from 15 to 44 m; however, 75:25 PF diets significantly fluctuated ± 3 percentage points as feed was augered from 15 to 44 m. Although, to our knowledge, the mechanism between feed augering and pellet deterioration is not

specifically documented in previous literature, we speculate that the differences observed for 75:25 PF diets augered from 15 to 44 m due could be due to increased shear force [35] between the auger and pellets. Shearing forces can cause deformation and subsequent breakage by pushing the top and bottom of a solid object in opposite directions [35]. As there were more pellets in the 75:25 PF diets, we speculate that there was more opportunity for pellets to be affected by the shear force of the auger.

An interaction between Time and Location was established for percent pellets ($P<0.0001$; Figure 3.3). At 0 m, percent pellets for augering Times 2, 3, and 4 were higher than augering Time 1. However, percent pellets decreased for all Times when augered from 0 to 15 m and 44 to 58 m. When augered from 15 to 44 m, no difference was established for Time. Over Time and Location, percent pellets acted in a similar manner as the interaction between PF and Location ($P<0.0001$; Figure 3.2). These data suggest that each Time feed is augered, similar pellets will be available at each feed pan Location.

A significant interaction between LAM, PF, and Location was established for surviving pellets ($P=0.044$; Figure 3.4). For mixer LAM, the main effect PF demonstrated a steady decrease in the number of surviving pellets across location, and 55:45 PF diets were significantly less durable than 75:25 PF diets. Furthermore, diets manufactured with PPLAM demonstrated a reduction in surviving pellets as feed was augered across location; however, surviving pellets for the 75:25 and 55:45 PF diets decreased similarly when PPLAM was utilized. These data demonstrate that PPLAM diets are less susceptible to attrition when compared to MLAM diets, and 55:45 PF diets manufactured using MLAM have less structural integrity post augering that 75:25 PF

diets manufactured using MLAM. These results can be supported by the findings of Loar and others [16], as it was determined that PPLAM create a more durable pellet than MLAM. Previous field studies have demonstrated that surviving pellets decline in the same manner as percent pellets [4, 11]. The current data supports previous field work findings [4, 11], as there were less surviving pellets (P=0.044; Figure 3.4) across Location.

The main effects of LAM, PF, and Location interacted significantly for the variable phytase activity (P=0.017; Table 3.5). Specifically, when MLAM was utilized, analyzed phytase activity was consistently low (~190 ftu/kg on average; 9% retention) across PF and Location. We speculate that this was due to protein denaturation, thus low retention (~9% retention). However, PPLAM diets, regardless of PF, demonstrated significant fluctuations in phytase activity (1603 ftu/kg at lowest; 2956 ftu/kg at highest; unconditioned mash at 2050 ftu/kg) across locations. As PPLAM diets were augered throughout the feed line, phytase activity increased as fines increased and pelleted decreased (P<0.0001; Figure 3.2).

These data agree with previous field work [11], as PPLAM diets demonstrated the highest level of phytase segregation upon feed augering (P=0.017; Table 3.5). Data in the current study shows consistently low phytase activity for MLAM diets (~9.3% retention). The phytase used in the current study was intended to be heat-stable; however, analyses suggest that it was not. Mixer LAM diets were manufactured with 2.44% mixer-added fat and conditioned for ten seconds at 78 ± 2°C [16, 17] in attempt to preserve enzyme retention/efficacy [16-18]. Analyses suggest that the majority of phytase for MLAM was likely denatured due to the heat and steam conditioning

parameters associated with pelleting [17, 36-39]. However, it is plausible that there was a limitation in the phytase assay itself [37] due to low repeatability and reproducibility [40].

For PPLAM diets, significantly higher phytase levels were found in the same locations that exhibited high fine quantities and low percent pellets (P=0.017; Table 3.5). Due to all of the phytase being applied to the outside of the pellet for PPLAM, data suggests that the outside of the pellet deteriorated when feed was augered throughout the feed line. Therefore, as PPLAM diets are augered and subsequently broken down, feed pans with higher concentrations of fines may contain the liquid ingredients applied to the outside of the pellet (i.e. phytase in this study).

These data suggest that feed pan Location may dictate the amount of nutrients broilers are receiving when PPLAM diets are augered throughout a commercial feed line. Depending on the original pellet to fine ratio and manufacturing technique, the observed segregation of phytase may allow some broilers to receive a phytase dosage much higher than the manufacturer's dosage threshold (super-dosed levels). Super-dosing phytase is when birds are fed unconventionally high doses of phytase (>2500 ftu/kg from *Aspergillus niger or Escherichia coli* strains*)* [41]. These differences in phytase consumed by a bird could potentially affect broiler performance and BW uniformity throughout the house [41-43]. Therefore, experiment 2 was conducted to determine if the observed changes in physical and subsequent phytase segregation were enough to elicit differences in heavy (d 28 to 56) broiler performance, uniformity, and processing.

Experiment 2: Broiler Performance (d 28 to 56) and Processing (d 57)

As previously mentioned, the augered diets in experiment 1 were collected from the commercial house and transported to a floor pen experimental facility to allow for replication.

Pellet to Fine Ratio Effects

In the results for live performance, broilers fed 75:25 PF diets demonstrated a 3 point reduction in d 28 to 42 FCR (P=0.0003), as well as a 2% increase in d 42 and 49 BW (P<0.0001 and P<0.0001, respectively) and 3% increase in d 28 to 56 BWG (P=0.015) when compared to broilers fed 55:45 PF diets (Table 3.6). Feeding broilers 75:25 vs. 55:45 PF diets also demonstrated a 1.7 and 2.7% increase in d 57 carcass and total breast weight, respectively (P=0.028 and P=0.048, respectively; Table 3.7). However, feeding birds 75:25 PF diets did not result in significant differences for any d 57 processing yields when compared to broilers fed 55:45 PF diets (P>0.05; Table 3.8).

Data in the current study agrees with previous PF research, where feeding more pellets (>75%) resulted in improved performance and processing variables when compared to diets containing less pellets (<55%) [6-10]. In addition, results from experiment 1 demonstrated a ~2.5 percentage point increase in surviving pellets for 75:25 PF diets when compared to 55:45 PF diets (P=0.044; Figure 3.4). Thus, the benefits of feeding 75:25 PF diets observed in the current study may be because more pellets survived augering.

Liquid Application Method Effects

Broilers fed PPLAM diets exhibited a 2 point decrease in d 28 to 42 FCR (P=0.007), as well as a 1.3 and 1.7% increase in d 42 and 49 BW (P=0.0008 and P<0.0001, respectively) when compared to broilers fed diets manufactured MLAM (Table 3.6). Furthermore, broilers that received PPLAM diets demonstrated a 3% increase in tender weight (P=0.015; Table 3.7) and a 3% increase in tender yield (P=0.017; Table 3.8) when compared to birds fed MLAM treatments.

These data demonstrate advantages to feeding diets manufactured with PPLAM. In the results from experiment 1, PPLAM diets exhibited over a 5.5 percentage point increase in pellets post feed augering than MLAM treatments (P<0.0001; Table 3.4), and diets manufactured with PPLAM had more surviving pellets than MLAM diets (P=0.044; Figure 3.4). Therefore, birds fed PPLAM diets potentially demonstrated advantages in BW, BWG, FCR, and tender weight and yield due to improved feed quality as compared to MLAM treatments. However, it should be noted that post-pellet LAM can potentially be harmful to heat-sensitive nutrients due to decreased levels of mixer-added fat [16, 17].

In the current study, we recognized the potential for protein denaturation when diets are manufactured with PPLAM; thus, feed was processed in a manner to avoid this (i.e. 1.00% mixer-added fat; 10 s steam conditioning at 78 ± 2°C). The results were potentially confounded due to decreased phytase retention for diets manufactured using MLAM (~9% retention). Consequently, broilers fed diets manufactured with PPLAM may have exhibited improvements in performance due to the increased phytase retention [38-40]. However, it must be noted that only phytase was tested; it is possible that other

nutrients were segregating and contributing to bird performance differences, as others were found to segregate in previous field work [4, 11].

Feed Pan Location Effects

Broilers fed diets that were augered from 0-30 m demonstrated a 1% increase in d 42 BW when compared to birds fed diets augered from 32-58 m (P=0.017; Table 3.6). Conversely, broilers fed diets augered from 32-58 m exhibited a 2.4% increase in d 42 to 49 BWG (P=0.012; Table 3.6). In addition, broilers fed treatments augered from 32-58 m demonstrated a 3% increase in d 57 tender (P=0.032; Table 3.8) when compared to broilers receiving treatments augered from 0-30 m.

In the results for experiment 1, percent pellets and surviving pellets steadily decreased across location (Figure 3.2 and 3.4, respectively). Previous research has determined that feeding diets with an increased PF can improve BW [8, 10]; thus, d 42 BW was likely affected by the amount of pellets available from 0-30 and 32-58 m. Since diets augered from 0-30 m had more available pellets than diets augered from 32-58 m, the observed increases in d 42 to 49 BWG and d 57 tender yield were not expected when broilers were fed diets augered from 32-58 vs. 0-30 m. Additionally, differences observed could be due to phytase segregation.

Interactive Effects of Pellet to Fine Ratio, Liquid Application Method, and Feed Pan Location

In the results for d 56 BW CV, a significant interaction between LAM, PF, and Location was established (P=0.034; Figure 3.5). For broilers fed diets manufactured using MLAM, there was no significant difference in d 56 CV for birds fed either PF (75:25 or 55:45) regardless of Location (0-30 or 32-58 m). For birds that received 75:25

PF diets manufactured using PPLAM and augered from 0 to 30 m, d 56 BW CV improved when compared to birds fed 55:45 PF diets manufactured using PPLAM and augered from 0 to 30 m, as well as birds fed 75:25 PF diets manufactured using PPLAM and augered from 32 to 58 m. However, birds fed 75:25 PF diets from 0 to 30 m and birds fed 55:45 PF diets augered from 32 to 58 m were similar.

The observed differences in d 56 BW CV may be attributable to the phytase segregation observed for PPLAM diets in experiment 1 (P=0.017; Table 3.5). As phytase, and potentially other ingredients, segregated throughout feed augering, broilers may not have received the adequate amount of nutrients required to maximize growth potential [44] due to the selection of favorable feed particles (pellets vs. fines) [45-46]. These data suggest that BW uniformity is affected by the distance in which feed travels throughout a feed line. In addition, if PPLAM diets are fed, BW uniformity of broilers at time of slaughter may differ greatly throughout a commercial house due to feed augering effects on nutrient segregation.

The main effects of PF, LAM, and Location interacted to establish significance for d 28 to 42 BWG. Broilers fed 75:25 PF diets manufactured utilizing PPLAM and augered from either location demonstrated an ~2.5% improvement in d 28 to 42 BWG when compared to any treatment combination containing 55:45 PF (P=0.028; Table 3.6). In addition, broilers fed 75:25 PF diets manufactured using MLAM and augered from 0-30 m exhibited a ~4.8% improvement in d 28 to 42 BWG when compared to any treatment combination containing 55:45 PF. However, broilers that received 75:25 PF diets manufactured using MLAM and augered from 32-58 m had comparable BWG to treatment combinations containing 55:45 PF.

The observed decrease in d 28 to 42 BWG when birds were fed 75:25 PF diets manufactured with MLAM and augered from 32-58 m may be attributed to the dramatic decrease in feed quality. In experiment 1, surviving pellet data indicated that 75:25 PF diets manufactured using MLAM were less durable across location than PPLAM diets (P=0.044; Figure 3.4). As research has demonstrated that small improvements in percent pellets can improve BWG [8, 10], current data suggests d 28 to 42 BWG in broilers fed 75:25 PF diets manufactured using MLAM was affected by the distance feed traveled within the feed line. This was presumably due to the increased rate of pellet deterioration. However, since we only observed phytase, it could be due to other nutrients segregating.

A significant PF x LAM interaction was established for d 49 BW (P=0.037; Table 3.6). Broilers fed 75:25 PF diets manufactured with PPLAM demonstrated a higher d 49 BW than any other treatment combination (P=0.037; Table 3.6). However, birds fed 75:25 PF diets manufactured utilizing MLAM and 55:45 PF diets manufactured with PPLAM were similar. Based upon the results from experiment 1, PPLAM and 75:25 PF diets had 10.5 percentage points more surviving pellets across location than MLAM and 55:45 PF diets (P=0.044; Figure 3.4). Thus, d 49 BW was likely ameliorated in broilers fed 75:25 PF diets manufactured with PPLAM when compared to broilers fed 55:45 PF diets manufactured with MLAM due to the improved feed quality observed at the feed pan post augering.

Lastly, an interaction between PF and Location was established for d 57 wing weight and yield (P=0.037 and P=0.035, respectively; Tables 3.7 and 3.8, respectively). Broilers fed 75:25 PF diets augered from 32-58 m demonstrated a 2.8% increase in wing

weight when compared to broilers fed 55:45 PF diets augered from 32-58 m; however, wing weights were comparable between 75:25 PF diets augered from 32-58 m and 75 and 55:45 PF diets augered from 0-30 m (Table 3.7). In addition, a 2.4% increase in wing yield was demonstrated in broilers fed 75:25 PF diets augered from 32-58 vs. 0-30 m (P=0.035; Table 3.8). Broilers fed diets containing 55:45 PF, augered from either Location, resulted in similar d 57 wing yields as compared to all PF and Location treatment combinations (Table 3.8).

Overall Summary

The results of the current study verify the results of field work that also demonstrated nutrient segregation was occurring throughout commercial poultry houses [4, 11]. Furthermore, this research established that differences in PF and Location can affect broiler performance. In addition, data suggests that manufacturing technique may percent pellets; PPLAM resulted in increased percent pellets (P<0.0001; Table 3.4) and surviving pellets (P=0.044; Figure 3.4) as diets were augered throughout a feed line when compared to MLAM diets.

In general, PPLAM can improve pellet quality [16], but PPLAM may adversely affect nutrient availability due to more frictional heat generated at the pellet die. Additionally, PPLAM may exacerbate phytase segregation (P=0.017; Table 3.5). However, the results may be confounded due to low phytase retention of MLAM diets (~9.3% retention). In general, percent pellets steadily declined across Location, regardless of PF (P<0.0001; Figure 3.2). The decrease in percent pellets may be attributed to decreased surviving pellets throughout feed augering (P=0.044; Figure 3.4). For PPLAM, phytase segregated from the outside of the pellet. These data demonstrate

that more segregation is likely to occur in PPLAM diets due to the attrition of pellets throughout augering.

Moreover, performance and processing benefits demonstrated in experiment 2 for broilers fed 75:25 PF diets and diets manufactured with PPLAM were likely associated with more high-quality pellets available for broiler consumption [6-10]. Overall, broilers fed 75:25 PF diets and PPLAM diets demonstrated a 1.3 to 2% increase d 42 and 49 BW, 2.5% increase in d 28 to 42 BWG, and 2 to 3 point reduction in d 28 to 42 FCR ($P<0.05$; Table 3.7). Feeding 75:25 PF diets resulted in a 3% increase in d 28 to 56 BWG ($P=0.015$; Table 3.7), 1.7% increase in carcass weight ($P=0.028$; Table 3.9), and 2.7% increase in total breast weight ($P=0.048$; Table 3.9). The benefits of feeding PPLAM diets observed in the current study may be confounded due to the previously mentioned low phytase retention (~9.3%) of the MLAM diets. However, we speculate that d 56 BW CV for broilers fed PPLAM diets was affected due to the segregation effects associated with augering PPLAM diets.

Ultimately, this was the first study to provide replicated data to determine PF and LAM effects on feed augering, physical and phytase segregation, and subsequent broiler performance. The current study only observed feed augering effects on one feed line; it is likely that feed quality will differ when augered throughout a whole house based upon feed line, feed pan location, and time in which the feed is augered. In addition, more nutrients may be segregating; thus, segregation effects should be investigated. Future research should determine the distribution of pellets and level of segregation that occurs when augering feed throughout a whole poultry feeding system.

Conclusions and Applications

1. Percent pellets and surviving pellets at point of consumption post augering were higher in 75:25 PF diets and PPLAM diets; this ultimately elicited a 2 to 3 point reduction in d 28 to 42 FCR, 1.3 to 2% increase in d 42 BW, 1.7 to 2% increase in d 49 BW, and ~2.5% increase in d 28 to 42 BWG, respectively. Furthermore, a 1.7% and 2.7% increase in d 57 carcass and total breast weight, respectively, were demonstrated when broilers were fed 75:25 vs. 55:45 PF diets.

2. Feed augering interactively affects nutrient segregation (phytase) and consequent BW uniformity due to manufacturing technique and distance traveled within the feed line. As PPLAM diets are augered, we speculate that attrition occurs to the outside of the pellet. Thus, poor CV in broilers may be a result of birds receiving different levels of nutrients at a given feed pan location within a commercial house.

3. This study demonstrates that creating high-quality pellets should be of importance to a commercial mill due to the observed effects that feed augering has on pellet quality, nutrient segregation, and subsequent d 28 to 56 bird performance.

Table 3.1 Nutritional composition of finisher broiler diets manufactured in experiment 1 and used for live growth performance in experiment 2[1]

	Finisher diet (28 to 56 d)
Ingredient, %	
Corn	67.11
Soybean meal (48% CP)	18.58
Meat and bone meal[2]	5.00
Corn DDGS[3]	5.00
Animal/vegetable blend fat[4]	2.44
Limestone	0.58
Dicalcium phosphate	0.05
Salt	0.28
Sodium bicarbonate	0.04
L-Lysine HCL	0.19
DL-Methionine	0.21
L-Threonine	0.05
Phytase enzyme[5]	0.005
Vitamin/mineral premix[6]	0.25
Choline chloride	0.10
Coban 90[7]	0.05
BMD 50[8]	0.08
Calculated nutrients	
ME, kcal/kg	3188
CP, %	18.33
Available Phosphorus, %	0.32
Total TSAA, %	0.70
Total Methionine, %	0.46
Total Lysine, %	0.90
Total Threonine, %	0.59
Calcium, %	0.75
Sodium, %	0.18

[1]Formulated to meet Ross x Ross 708 broiler guidelines; finisher diets were manufactured in experiment 1 and fed from d 28 to 56 in experiment 2 to measure live performance and processing characteristics
[2]H. J. Baker and Bro., Little Rock, AR
[3]Distillers dried grains with solubles
[4]Animal-vegetable oil blend; diets manufactured using mixer LAM had all fat (2.44%) added in the mixer, and diets manufactured using post-pellet LAM had 1.00% fat added in the mixer with the remaining 1.44% added post-pellet
[5]Heat stable liquid phytase; DSM Nutritional Products Inc., Parsippany, NJ
[6]Provided per kilogram of diet: 0.02% manganese; 0.02% zinc; 0.01% iron; 0.0025% copper; 0.0003% iodine; 0.00003% selenium; 0.69 mg of folic acid; 386 mg of choline; 6.61 mg of riboflavin; 0.03 mg of biotin; 1.38 mg of vitamin B_6; 27.56 mg of niacin; 6.61 mg of pantothenic acid; 2.20 mg of thiamine; 0.83 mg of menadione; 0.01 mg of vitamin B_{12}; 16.53 IU of vitamin E; 2,133 ICU of vitamin D_3; and 7,716 IU of vitamin A
[7]Active drug ingredient monensin, USP, 90.7 g/lb inclusion of cocciodiostat; Elanco Animal Health, Greenfield, IN
[8]Active drug ingredient bacitracin methylene disalicylate, 50 g/lb inclusion; Zoetis, Florham Park, NJ

Table 3.2 Manufacturing variables and beginning pellet quality for the finisher diets used in experiment 1 and 2 (descriptive data)

Manufacturing technique[1]	Pellets (%)	PDI[2] (%)	MPDI[3] (%)	New Holmen[4] (%)
75:25 pellet to fine, mixer LAM[5]	73.4	90.5	86.5	88.0
55:45 pellet to fine, mixer LAM	53.3	88.7	84.2	82.7
75:25 pellet to fine, post-pellet LAM	78.3	91.6	88.9	89.0
55:45 pellet to fine, post-pellet LAM	55.5	91.4	89.2	89.1

[1]Manufacturing technique: all diets were pelleted identically, using a 4.76 x 38.1 mm die, a production rate of 0.816 tonne/h, a 10 sec steam conditioning pressure of 262 kPa, and a steam conditioning temperature of 78°C ± 2°C. Diets were first manufactured to contain 75:25 pellet to fine ratio. A portion of the original diet was ground to create fines, and the fines were subsequently added back into the original diet to create a 55:45 pellet to fine ratio. Diets manufactured using mixer liquid application method (LAM) had all supplemental fat (2.44%) and phytase (0.005%) inclusion added in the mixer. Diets manufactured utilizing post-pellet LAM had 1.00% supplemental fat added in the mixer, and the remaining 1.44% supplemental fat and 0.005% phytase were added post-pellet.

[2]PDI= pellet durability index; percentage determined by placing 500 g of sifted pellets into a Pfost tumbler (Gamet Manufacturing Inc., Saint Paul, MN). Samples were tumbled for 10 min at 50 rpm. The sample was then sifted again and weighed. Pellet durability index was calculated as the percent of sifted pellets retained after tumbling.

[3]MPDI = modified pellet durability index; percentage determined similar to PDI, with the exception of the addition of 5 13-mm hexagonal nuts to the 500 g sample before tumbling.

[4]Surviving pellets percentage determined by placing 100 g of sifted pellets into the New Holmen's Pellet Tester (NHPT100; TekPro Ltd., North Walsham, Norfolk, UK). The pellets were cascaded in an air stream for 30 sec, causing them to collide with each other and the perforated hard surfaces of the test chamber. The fines were removed as they were blown through the perforated screen. The surviving pellets were then removed and weighed again. Pellet durability was calculated as the percent of surviving pellets retained after sampling.

[5]LAM = liquid application method

Table 3.3 Treatment outline for experiment 2

LAM[1]	PF[2]	Augering Location[3]
Mixer	55:45	0-30
		32-58
	75:25	0-30
		32-58
Post-pellet	55:45	0-30
		32-58
	75:25	0-30
		32-58

[1]LAM = liquid application method; supplemental fat and phytase addition; diets manufactured utilizing mixer LAM had all of the fat (2.44%) and phytase (0.005%) added in the mixer prior to pelleting; diets manufactured utilizing post pellet LAM had 1% fat added in the mixer prior to pelleting, with the remaining fat (1.44%) and phytase (0.005%) added via post-pellet application

[2]PF = pellet to fine ratio; either 55% intact pellets and 45% ground pellets or 75% intact pellets and 25% ground pellets; diets were originally manufactured to contain 75:25 PF, and a portion of this diet was ground to create the 55:45 PF diets.

[3]Location = location in which feed was collected post augering via commercial feed system; feed was augered from the line hopper to the end pan, and feed was collected from 0-30 m (hopper to migration fence) and 32-58 m (migration fence to end pan) on a commercial feed line.

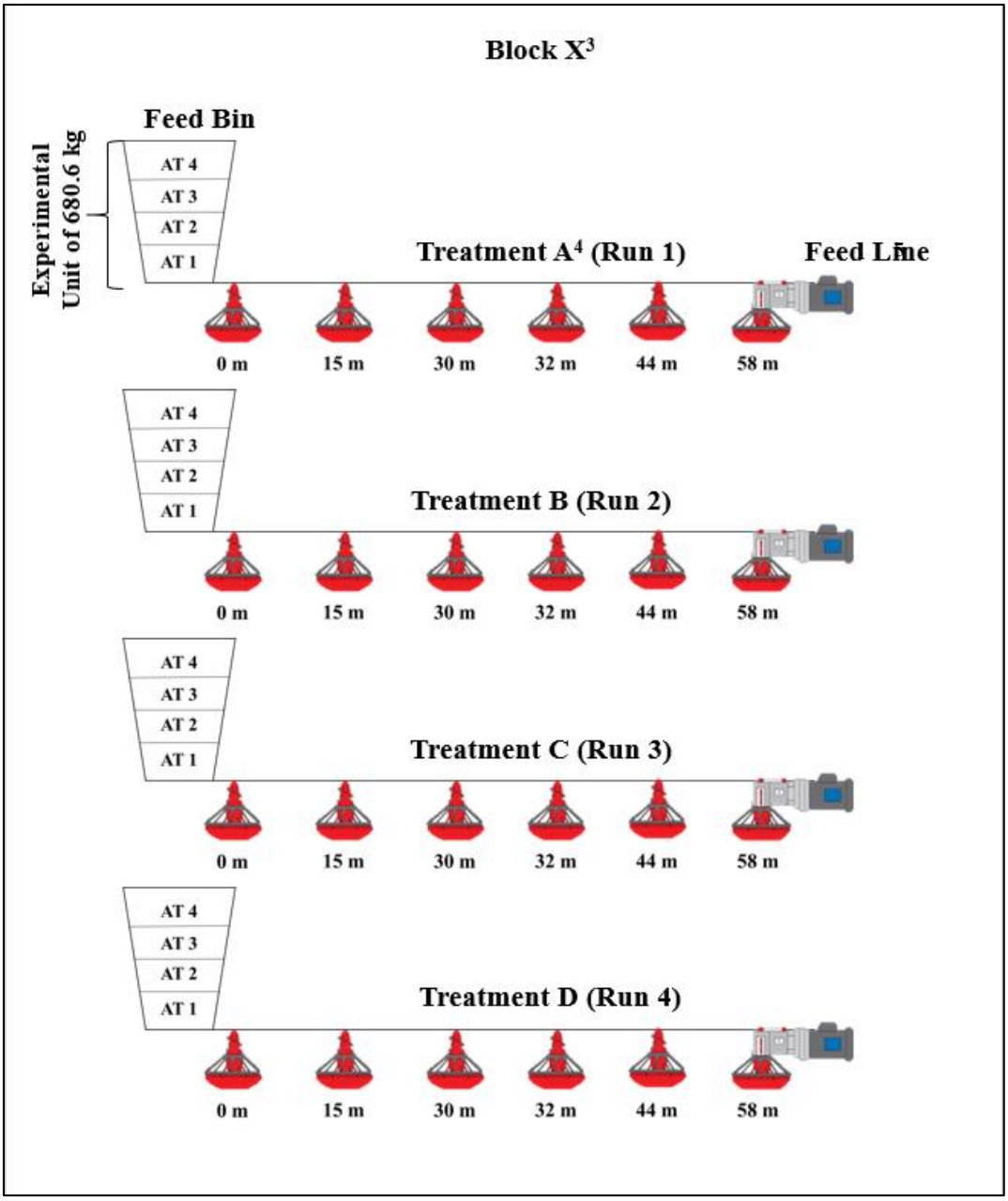

Figure 3.1 Toy example of augering time[1] across feed pan location[2] for treatments

[1]Augering time = AT; each time the feed line was entirely filled (n=4) and subsequently sampled for each treatment. The feed line was completely charged with feed; samples were obtained from 30 and 58 m and the feed augering line was then cleared. The remaining samples were then taken from 0, 15, 32, and 44 m, and every feed pan between sampling locations on the feed line was emptied. This process was repeated four times for each run; there were four runs per block (4 blocks total)
[2]Feed pan location = location in which feed was collected post augering via commercial feed system; feed was augered from the line hopper to the end pan, and feed was sampled from pans at 0, 15, 30, 32, 44, and 58 m on the feed line.
[3]Block X = toy example block; 4 blocks total in experiment with run order randomized in each block
[4]Treatment A-D = example treatments (labeled as A-D for this toy example only); treatments in the current study were manufactured to contain 75:25 or 55:45 pellet to fine ratio utilizing either mixer or post-pellet liquid application method and were augered as part of a randomized complete block design
[5]Grower Select®, Hog Slat, Inc., Newton Grove, NC.

Table 3.4 Percent pellets observed post feed augering for diets manufactured utilizing two liquid application methods and two pellet to fine ratios (experiment 1)

LAM[1]	PF[2]	Location[3] (m)	Percent Pellets[4] (%)
-	55:45	0	55.24^{e}
		15	41.31^{h}
		30	42.54^{gh}
		32	42.74^{g}
		44	41.50^{gh}
		58	27.70^{i}
	75:25	0	77.31^{a}
		15	64.37^{d}
		30	66.44^{c}
		32	67.87^{b}
		44	65.97^{c}
		58	45.65^{f}
SEM			0.4746
Marginal means			
Mixer	-	-	50.35^{b}
Post-pellet			56.09^{a}
-	55:45	-	41.84
	75:25		64.60
SEM			0.5968
-	-	0	66.28
		15	52.84
		30	54.49
		32	55.30
		44	53.74
		58	36.67
SEM			0.3356
Main effect and interaction probabilities			
LAM			<0.0001
PF			<0.0001
Location			<0.0001
PF x Location			<0.0001
LAM x PF x Location			0.5874

[a-i]Means within a column not sharing a common superscript differ ($P \leq 0.05$).
[1]LAM = liquid application method; supplemental fat and phytase addition; diets manufactured utilizing mixer LAM had all of the fat (2.44%) and phytase (0.005%) added in the mixer prior to pelleting; diets manufactured utilizing post pellet LAM had 1% fat added in the mixer prior to pelleting, with the remaining fat (1.44%) and phytase (0.005%) added via post-pellet application
[2]PF = pellet to fine ratio; either 55% intact pellets and 45% ground pellets or 75% intact pellets and 25% ground pellets; diets were originally manufactured to contain 75:25 PF, and a portion of this diet was ground to create the 55:45 PF diets.
[3]Location = location in which feed was collected post augering via commercial feed system; feed was augered from the line hopper to the end pan, and feed was sampled from pans at 0, 15, 30, 32, 44, and 58 m on the feed line.
[4]Percent pellets = (intact pellet sample weight/total sample weight)*100%. The total sample was initially weighed and subsequently sifted using a No. 6 American Society for Testing and Materials screen (metric equivalent = 3.35 mm) to separate intact pellets from fines; the pellet sample was then weighed and percent pellets was calculated

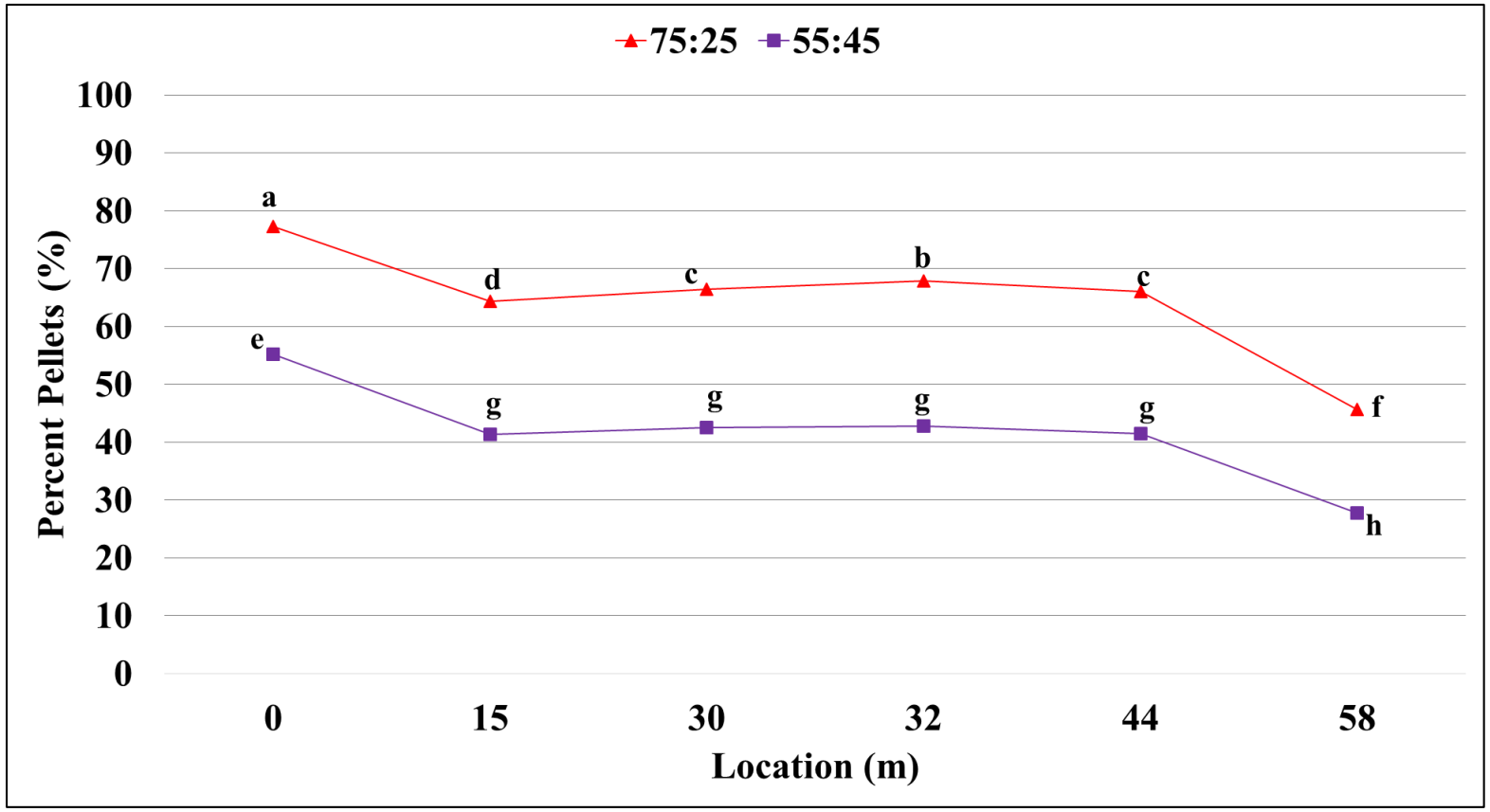

Figure 3.2 Interactive effects* of pellet to fine ratio[1] and location[2] on percent pellets[3] post feed augering (experiment 1)

*P<0.0001; SEM=0.102

[1]PF = pellet to fine ratio; either 55% intact pellets and 45% ground pellets or 75% intact pellets and 25% ground pellets; diets were originally manufactured to contain 75:25 PF, and a portion of this diet was ground to create the 55:45 PF diets.

[2]Location = location in which feed was collected post augering via commercial feed system; feed was augered from the line hopper to the end pan, and feed was sampled from pans at 0, 15, 30, 32, 44, and 58 m on the feed line.

[3]Percent pellets = (intact pellet sample weight/total sample weight)*100%. The total sample was initially weighed and subsequently sifted using a No. 6 American Society for Testing and Materials screen (metric equivalent = 3.35 mm) to separate intact pellets from fines; the pellet sample was then weighed and percent pellets was calculated

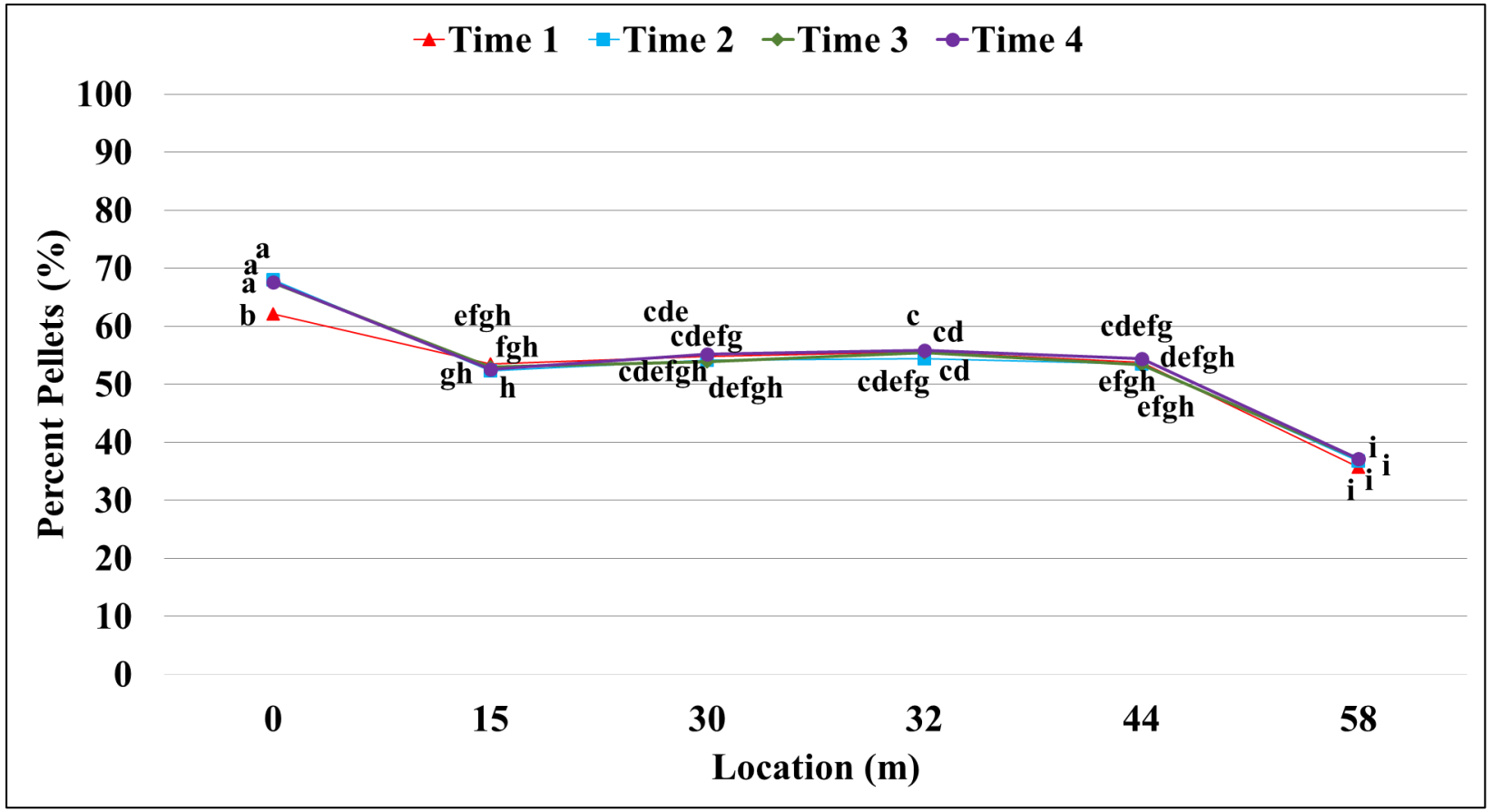

Figure 3.3 Interactive effects* of augering time[1] and location[2] on percent pellets[3]

*P<0.0001; SEM=0.6712

[1]Augering time = each time the feed line was completely filled (n=4) and subsequently sampled for each treatment

[2]Location = location in which feed was collected post augering via commercial feed system; feed was augered from the line hopper to the end pan, and feed was sampled from pans at 0, 15, 30, 32, 44, and 58 m on the feed line.

[3]Percent pellets = (intact pellet sample weight/total sample weight)*100%. The total sample was initially weighed and subsequently sifted using a No. 6 American Society for Testing and Materials screen (metric equivalent = 3.35 mm) to separate intact pellets from fines; the pellet sample was then weighed and percent pellets was calculated

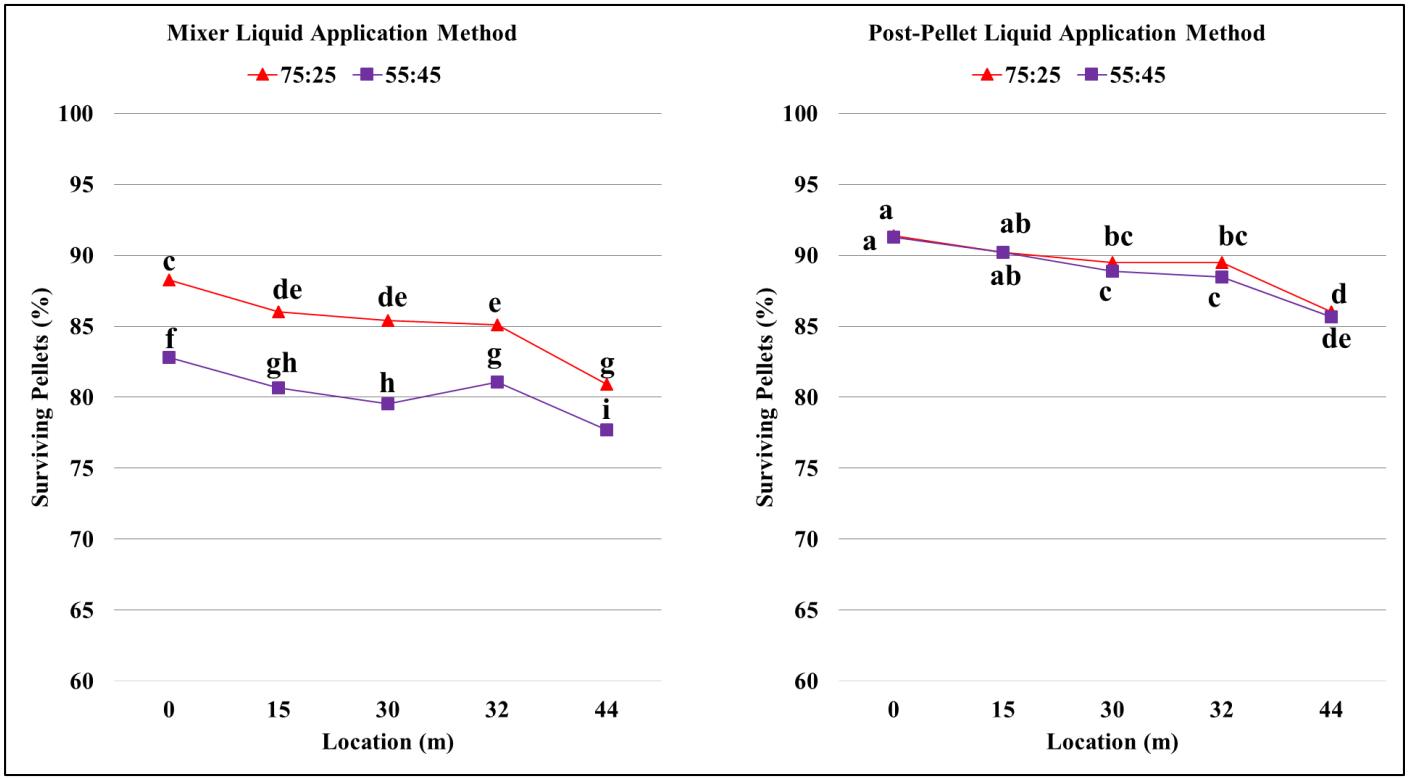

Figure 3.4 Interactive effects* of pellet to fine ratio[1], liquid application method[2], and location[3] on percent surviving pellets[4] (experiment 1)

*P=0.044; SEM=0.468

[1]LAM = liquid application method; supplemental fat and phytase addition; diets manufactured utilizing mixer LAM had all of the fat (2.44%) and phytase (0.005%) added in the mixer prior to pelleting; diets manufactured utilizing post pellet LAM had 1% fat added in the mixer prior to pelleting, with the remaining fat (1.44%) and phytase (0.005%) added via post-pellet application

[2]PF = pellet to fine ratio; either 55% intact pellets and 45% ground pellets or 75% intact pellets and 25% ground pellets; diets were originally manufactured to contain 75:25 PF, and a portion of this diet was ground to create the 55:45 PF diets.

[3]Location = location in which feed was collected post augering via commercial feed system; feed was augered from the line hopper to the end pan, and feed was sampled from pans at 0, 15, 30, 32, 44, and 58 m on the feed line. Surviving pellet data in this graph only include first 5 sampling location (0-44 m)

[4]Surviving pellets = (gram weight of surviving intact pellets/100 g sifted pellet sample)*100%. Percentage was determined by placing 100 g of sifted pellets into the New Holmen's Pellet Tester (NHPT100; TekPro Ltd., North Walsham, Norfolk, UK). The pellets were cascaded in an air stream for 30 sec, causing them to collide with each other and the perforated hard surfaces of the test chamber. The fines were removed as they were blown through the perforated screen. The surviving pellets were then removed and weighed again. Pellet durability was calculated as the percent of surviving pellets retained after sampling

Table 3.5 Analyzed phytase activity of each diet post-feed augering (experiment 1)

LAM[1]	PF[2]	Location[3] (m)	Relative Phytase[4] (%)	Phytase Activity (FTU/kg)
Mixer	55:45	0	10.65^{f}	218.40^{f}
		15	9.87^{f}	202.43^{f}
		44	9.58^{f}	196.43^{f}
		58	10.09^{f}	206.75^{f}
	75:25	0	8.86^{f}	181.55^{f}
		15	8.58^{f}	175.78^{f}
		44	8.00^{f}	164.03^{f}
		58	8.99^{f}	184.22^{f}
Post-pellet	55:45	0	86.16^{e}	1766.27^{e}
		15	102.71^{cd}	2105.60^{cd}
		44	100.47^{d}	2059.69^{d}
		58	113.08^{bc}	2318.20^{bc}
	75:25	0	78.20^{e}	1603.00^{e}
		15	123.35^{b}	2528.61^{b}
		44	103.11^{cd}	2113.82^{cd}
		58	144.23^{a}	2956.79^{a}
Marginal means				
Mixer	-	-	9.33	191.21
Post-pellet			106.41	2181.51
-	55:45	-	55.33	1134.22
	75:25		60.41	1238.50
SEM			2.930	60.06
-	-	0	45.97	942.31
		15	61.13	1253.10
		44	55.29	1133.49
		58	69.10	1416.49
SEM			2.189	44.88
Main effect and interaction probabilities				
LAM			<0.0001	<0.0001
PF			0.2508	0.2508
Location			<0.0001	<0.0001
LAM x PF x Location			0.0166	0.0166

[a-f]Means within a column not sharing a common superscript differ ($P \leq 0.05$).

[1]LAM = liquid application method; supplemental fat and phytase addition; diets manufactured utilizing mixer LAM had all of the fat (2.44%) and phytase (0.005%) added in the mixer prior to pelleting; diets manufactured utilizing post pellet LAM had 1% fat added in the mixer prior to pelleting, with the remaining fat (1.44%) and phytase (0.005%) added via post-pellet application

[2]PF = pellet to fine ratio; either 55% intact pellets and 45% ground pellets or 75% intact pellets and 25% ground pellets; diets were originally manufactured to contain 75:25 PF, and a portion of this diet was ground to create the 55:45 PF diets.

[3]Location = location in which feed was collected post augering via commercial feed system; feed was augered from the line hopper to the end pan, and feed was sampled from pans at 0, 15, 30, 32, 44, and 58 m on the feed line. Analyzed phytase data in this table only include the sampling locations of 0, 15, 44, and 58 m due to the greatest difference in percent pellets observed between these locations (Table 3.4; P<0.0001).

[4]Relative phytase = (analyzed phytase activity/2050 FTU/kg phytase activity in unconditioned mash samples)*100%. Phytase activity was analyzed (Eurofins Analytical Lab, Des Moines, IA) utilizing the standard AOAC 2000.12 procedure, and analyzed sample phytase activity was related back to the phytase activity of unconditioned mash sample (2050 FTU/kg).

Table 3.6 Effects of liquid application method, pellet to fine ratio, and location on d 28 to 56 live performance (experiment 2)

LAM[1]	PF[2]	Location[3] (m)	D 28-42 FCR	D42 BW (kg)	D 28-42 BWG[4] (kg)	D 42-49 FCR	D49 BW (kg)	D 42-49 BWG (kg)	D 28-49 FCR	D 28-49 BWG (kg)	D 49-56 FCR	D 49-56 BWG (kg)	D 28-56 FCR	D 28-56 BWG (kg)
Mixer	55:45	0-30	1.78	3.08	1.64^{b}	2.09	3.89	0.81	1.86	2.48	2.50	0.69^{a}	1.99	3.23
		32-58	1.80	3.07	1.63^{b}	2.08	3.92	0.83	1.88	2.50	3.01	0.61^{b}	2.05	3.11
	75:25	0-30	1.74	3.17	1.73^{a}	2.13	3.97	0.80	1.84	2.58	3.00	0.59^{b}	2.01	3.26
		32-58	1.77	3.08	1.64^{b}	2.04	3.93	0.84	1.86	2.50	2.59	0.62^{ab}	2.00	3.21
Post-pellet	55:45	0-30	1.77	3.11	1.67^{b}	2.07	3.95	0.83	1.86	2.52	2.79	0.61^{b}	2.04	3.17
		32-58	1.76	3.09	1.65^{b}	2.07	3.92	0.83	1.89	2.45	2.60	0.63^{ab}	2.03	3.09
	75:25	0-30	1.73	3.19	1.75^{a}	2.11	4.05	0.83	1.84	2.61	2.77	0.60^{b}	2.00	3.24
		32-58	1.74	3.19	1.76^{a}	2.03	4.06	0.86	1.86	2.62	2.85	0.59^{b}	2.03	3.30
SEM			0.0111	0.0177	0.0182	0.0350	0.0232	0.0141	0.0191	0.0358	0.1982	0.0250	0.0250	0.0579
Mixer	55:45	-	1.79	3.08	1.64^{c}	2.08	3.90^{c}	0.82	1.87	2.49	2.76	0.65	2.02	3.17
	75:25		1.76	3.13	1.68^{b}	2.09	3.95^{b}	0.82	1.85	2.54	2.79	0.60	2.01	3.24
Post-pellet	55:45		1.77	3.10	1.66^{bc}	2.07	3.94^{bc}	0.83	1.88	2.49	2.70	0.62	2.03	3.13
	75:25		1.74	3.19	1.76^{a}	2.07	4.06^{a}	0.84	1.85	2.62	2.81	0.60	2.02	3.27
Mixer	-	0-30	1.76	3.13	1.68	2.11	3.93	0.81	1.85	2.53	2.75	0.64	2.00	3.24
		32-58	1.78	3.08	1.63	2.06	3.92	0.84	1.87	2.50	2.80	0.62	2.03	3.16
Post-pellet		0-30	1.75	3.15	1.71	2.09	4.00	0.83	1.85	2.57	2.78	0.60	2.02	3.20
		32-58	1.75	3.14	1.71	2.05	3.99	0.84	1.88	2.54	2.73	0.61	2.03	3.20
-	55:45	0-30	1.77	3.09	1.65	2.08	3.92	0.82	1.86	2.50	2.65	0.65	2.01	3.20
		32-58	1.78	3.08	1.64	2.07	3.92	0.83	1.89	2.48	2.81	0.62	2.04	3.10
	75:25	0-30	1.74	3.18	1.74	2.12	4.01	0.82	1.84	2.60	2.88	0.59	2.01	3.25
		32-58	1.75	3.14	1.70	2.04	4.00	0.85	1.86	2.56	2.72	0.61	2.02	3.25
SEM			0.0079	0.0125	0.0129	0.0247	0.0164	0.0099	0.0135	0.0253	0.1402	0.0177	0.0177	0.0410
Marginal means														
Mixer	-	-	1.77^{a}	3.10^{b}	1.66^{b}	2.09	3.93^{b}	0.82	1.86	2.52	2.77	0.63	2.01	3.20
Post-pellet			1.75^{b}	3.14^{a}	1.71^{a}	2.07	4.00^{a}	0.84	1.87	2.55	2.75	0.61	2.03	3.20
-	55:45	-	1.78^{a}	3.09^{b}	1.65^{b}	2.08	3.92^{b}	0.83	1.87	2.49^{b}	2.73	0.63	2.03	3.15^{b}
	75:25		1.75^{b}	3.16^{a}	1.72^{a}	2.08	4.00^{a}	0.83	1.85	2.58^{a}	2.80	0.60	2.01	3.25^{a}
-	-	0-30	1.75	3.14^{a}	1.70	2.10	3.97	0.82^{b}	1.85	2.55	2.76	0.62	2.01	3.22
		32-58	1.77	3.11^{b}	1.67	2.06	3.96	0.84^{a}	1.87	2.52	2.76	0.61	2.03	3.18
SEM			0.0056	0.0088	0.0091	0.0175	0.0116	0.0070	0.0096	0.0179	0.0991	0.0125	0.0125	0.0290
Main effect and interaction probabilities														
LAM			0.0073	0.0008	0.0006	0.4919	0.0001	0.1680	0.7408	0.1676	0.8824	0.2787	0.4899	0.9552
PF			0.0003	0.0001	0.0001	0.8566	0.0001	0.5942	0.0903	0.0005	0.6085	0.0897	0.3773	0.0153
Location			0.1018	0.0168	0.0683	0.0896	0.6009	0.0120	0.0796	0.2890	0.9820	0.6699	0.3348	0.2865
LAM x PF			0.8802	0.0735	0.0452	0.9495	0.0374	0.5691	0.9488	0.1225	0.7857	0.4335	0.9822	0.3943
LAM x Location			0.1014	0.1723	0.0534	0.7137	0.9134	0.3586	0.9165	0.8775	0.7110	0.4651	0.7250	0.3210
PF x Location			0.5457	0.2035	0.3665	0.1282	0.8445	0.2800	0.9832	0.8858	0.2510	0.2055	0.6076	0.2219
LAM x PF x Location			0.7915	0.0816	0.0276	0.9951	0.1172	0.7720	0.8480	0.0740	0.0372	0.0455	0.1631	0.5885

[a-c]Means within a column not sharing a common superscript differ ($P \leq 0.05$).

[1]Supplemental fat and phytase addition; diets manufactured utilizing mixer LAM had all of the fat (2.44%) and phytase (0.005%) added in the mixer prior to pelleting; diets manufactured utilizing post-pellet LAM had 1% fat added in the mixer prior to pelleting, with the remaining fat (1.44%) and phytase (0.005%) added via post pellet application

[2]PF = pellet to fine ratio; either 55% intact pellets and 45% ground pellets or 75% intact pellets and 25% ground pellets; diets were originally manufactured to contain 75:25 PF, and a portion of this diet was ground to create the 55:45 PF diets.

[3]Location = location in which feed was collected post augering via commercial feed system; feed was augered from the line hopper to the end pan, and feed was collected from 0-30 m (feed hopper to migration fence) and 32-58 m (migration fence to end pan) on a commercial feed line.

[4]BWG = average body weight gain

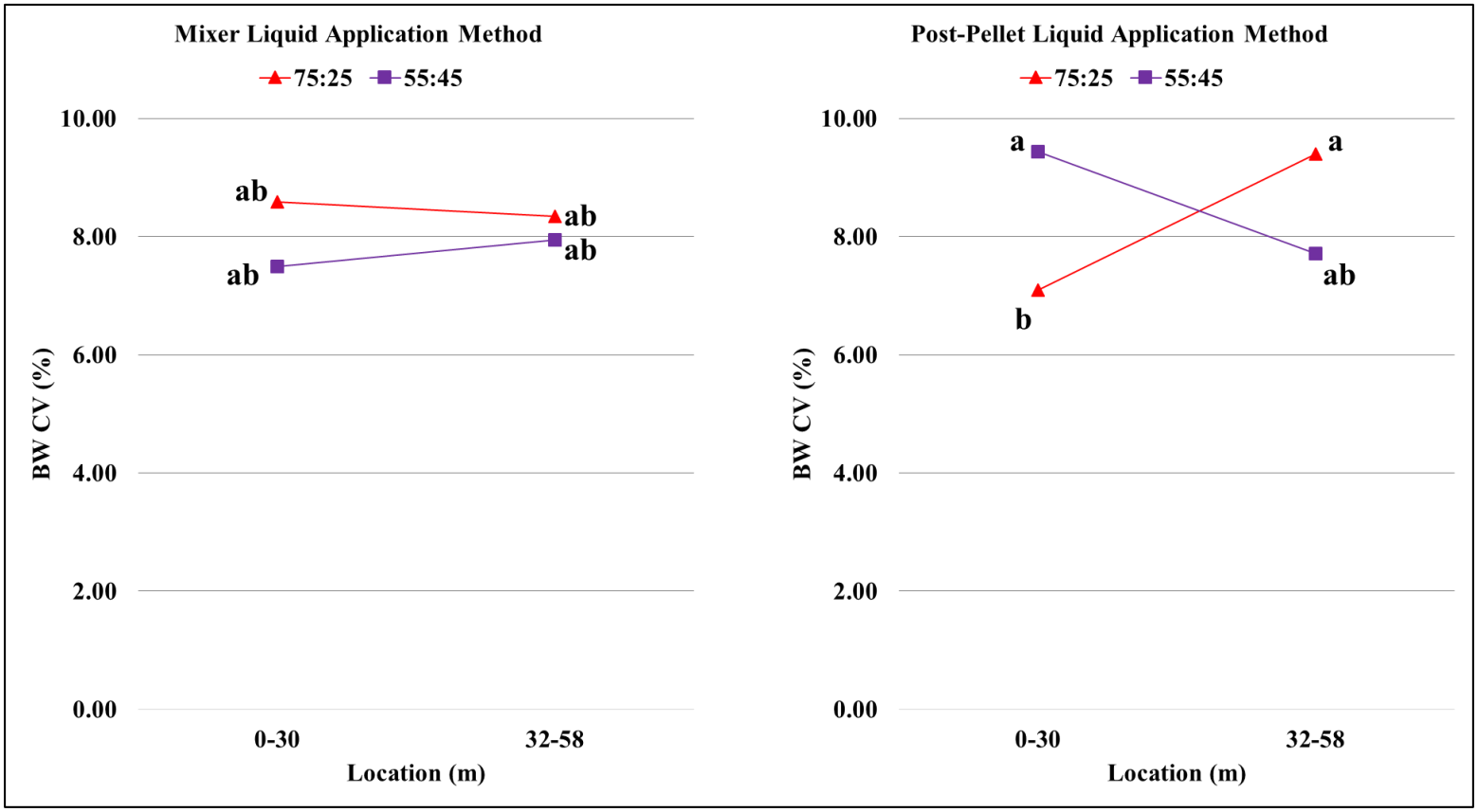

Figure 3.5 Interactive effects* of pellet to fine ratio[1], liquid application method[2], and location[3] on d 56 BW CV (experiment 2)

*P=0.034; SEM=0.795

[1]Supplemental fat and phytase addition; diets manufactured utilizing mixer LAM had all of the fat (2.44%) and phytase (0.005%) added in the mixer prior to pelleting; diets manufactured utilizing post-pellet LAM had 1% fat added in the mixer prior to pelleting, with the remaining fat (1.44%) and phytase (0.005%) added via post pellet application

[2]PF = pellet to fine ratio; either 55% intact pellets and 45% ground pellets or 75% intact pellets and 25% ground pellets; diets were originally manufactured to contain 75:25 PF, and a portion of this diet was ground to create the 55:45 PF diets.

[3]Location = location in which feed was collected post augering via commercial feed system; feed was augered from the line hopper to the end pan, and feed was collected from 0-30 m (hopper to migration fence) and 32-58 m (migration fence to end pan) on a commercial feed line

Table 3.7 Effects of liquid application method, pellet to fine ratio, and augering location on d 57 processing weights (experiment 2)

LAM[1]	PF[2]	Location[3] (m)	Carcass Wt. (kg)	Total Breast[4] (kg)	Breast[5] Wt. (kg)	Tender[6] Wt. (kg)	Drum Wt. (kg)	Thigh Wt. (kg)	Wing Wt. (kg)	Fat Pad[7] Wt. (kg)
Mixer	55:45	0-30	3.39	1.07	0.899	0.174	0.422	0.551	0.351	0.073
		32-58	3.37	1.08	0.905	0.178	0.417	0.540	0.351	0.070
	75:25	0-30	3.40	1.10	0.923	0.180	0.418	0.551	0.346	0.067
		32-58	3.43	1.09	0.906	0.183	0.412	0.541	0.355	0.073
Post-pellet	55:45	0-30	3.38	1.09	0.908	0.179	0.413	0.546	0.349	0.069
		32-58	3.33	1.08	0.895	0.189	0.409	0.541	0.341	0.075
	75:25	0-30	3.44	1.11	0.928	0.186	0.425	0.557	0.352	0.072
		32-58	3.45	1.12	0.929	0.187	0.426	0.557	0.357	0.076
SEM			0.0379	0.0167	0.0148	0.0038	0.0054	0.0078	0.0036	0.0028
Mixer	55:45	-	3.38	1.08	0.902	0.176	0.420[ab]	0.546	0.351[ab]	0.071
	75:25		3.41	1.10	0.915	0.181	0.415[ab]	0.546	0.350[ab]	0.070
Post-pellet	55:45		3.36	1.09	0.901	0.184	0.411[b]	0.543	0.345[b]	0.072
	75:25		3.44	1.12	0.928	0.187	0.426[a]	0.557	0.355[a]	0.074
Mixer	-	0-30	3.39	1.09	0.911	0.177	0.420	0.551	0.348	0.069
		32-58	3.40	1.09	0.906	0.180	0.415	0.541	0.353	0.071
Post-pellet		0-30	3.41	1.10	0.918	0.183	0.419	0.552	0.351	0.070
		32-58	3.39	1.10	0.912	0.188	0.418	0.549	0.349	0.075
-	55:45	0-30	3.38	1.08	0.903	0.177	0.418	0.548	0.350[ab]	0.070
		32-58	3.35	1.08	0.900	0.183	0.413	0.541	0.346[b]	0.072
	75:25	0-30	3.42	1.11	0.925	0.183	0.421	0.554	0.349[ab]	0.069
		32-58	3.44	1.10	0.918	0.185	0.419	0.549	0.356[a]	0.074
SEM			0.0268	0.0118	0.0104	0.0027	0.0039	0.0055	0.0025	0.0020
Marginal means										
Mixer	-	-	3.40	1.09	0.908	0.179[b]	0.417	0.546	0.351	0.070
Post-pellet			3.40	1.10	0.915	0.185[a]	0.418	0.550	0.350	0.073
-	55:45	-	3.37[b]	1.08[b]	0.902	0.180	0.416	0.544	0.348	0.071
	75:25		3.43[a]	1.11[a]	0.921	0.184	0.420	0.552	0.352	0.072
-	-	0-30	3.40	1.09	0.914	0.180	0.420	0.551	0.349	0.070
		32-58	3.39	1.09	0.909	0.184	0.416	0.545	0.351	0.073
SEM			0.0190	0.0084	0.0074	0.0019	0.0027	0.0039	0.0018	0.0014
Main effect and interaction probabilities										
LAM			0.8800	0.2635	0.5267	0.0151	0.7845	0.4328	0.7206	0.2509
PF			0.0281	0.0476	0.0622	0.1351	0.2289	0.1895	0.0672	0.8872
Location			0.7582	0.9269	0.6037	0.1099	0.3728	0.2411	0.5529	0.0719
LAM x PF			0.3053	0.6312	0.4971	0.5997	0.0143	0.2271	0.0488	0.3425
LAM x Location			0.6537	0.9423	0.9892	0.7108	0.5527	0.4805	0.1895	0.4416
PF x Location			0.3213	0.6850	0.8232	0.3602	0.7969	0.8271	0.0374	0.3830
LAM x PF x Location			0.9774	0.5255	0.3876	0.5732	0.6714	0.8537	0.7512	0.2305

[a-b]Means within a column not sharing a common superscript differ ($P \leq 0.05$).

[1]Supplemental fat and phytase addition; diets manufactured utilizing mixer LAM had all of the fat (2.44%) and phytase (0.005%) added in the mixer prior to pelleting; diets manufactured utilizing post-pellet LAM had 1% fat added in the mixer prior to pelleting, with the remaining fat (1.44%) and phytase (0.005%) added via post pellet application

[2]PF = pellet to fine ratio; either 55% intact pellets and 45% ground pellets or 75% intact pellets and 25% ground pellets; diets were originally manufactured to contain 75:25 PF, and a portion of this diet was ground to create the 55:45 PF diets.

[3]Location = location in which feed was collected post augering via commercial feed system; feed was augered from the line hopper to the end pan, and feed was collected from 0-30 m (feed hopper to migration fence) and 32-58 m (migration fence to end pan) on a commercial feed line.

[4]Total Breast = pectoralis major plus pectoralis minor.

[5]Breast = pectoralis major

[6]Tender = pectoralis minor

[7]Fat pad = abdominal fat pad

Table 3.8 Effects of liquid application method, pellet to fine ratio, and augering location on d 57 processing yields relative to d 56 live body weight (experiment 2)

LAM[1]	PF[2]	Location[3] (m)	Carcass (%)	Total Breast[4] (%)	Breast[5] (%)	Tender[6] (%)	Drumstick (%)	Thigh (%)	Wing (%)	Fat Pad[7] (%)
Mixer	55:45	0-30	73.35	23.21	19.45	3.76	9.14	11.92	7.59	1.57
		32-58	73.59	23.65	19.76	3.89	9.12	11.81	7.67	1.53
	75:25	0-30	73.23	23.79	19.90	3.88	9.01	11.88	7.45	1.44
		32-58	74.62	23.70	19.73	3.97	8.96	11.78	7.73	1.58
Post-pellet	55:45	0-30	73.46	23.62	19.72	3.90	8.99	11.86	7.58	1.49
		32-58	72.97	23.74	19.61	4.13	8.97	11.85	7.46	1.64
	75:25	0-30	73.88	23.92	19.92	4.00	9.13	11.98	7.45	1.53
		32-58	73.90	23.92	19.90	4.02	9.15	11.95	7.65	1.64
SEM			0.6419	0.3065	0.2742	0.0773	0.1159	0.1456	0.0642	0.0628
Mixer	55:45	-	73.47	23.43	19.60	3.83	9.13	11.86	7.63	1.55
	75:25		73.92	23.75	19.82	3.93	8.99	11.83	7.59	1.51
Post-pellet	55:45		73.21	23.68	19.67	4.01	8.98	11.86	7.52	1.56
	75:25		73.89	23.92	19.91	4.01	9.14	11.97	7.61	1.59
Mixer	-	0-30	73.29	23.50	19.67	3.82	9.08	11.90	7.52[b]	1.50
		32-58	74.11	23.68	19.74	3.93	9.04	11.80	7.70[a]	1.56
Post-pellet		0-30	73.67	23.77	19.82	3.95	9.06	11.92	7.58[ab]	1.51
		32-58	73.44	23.83	19.76	4.08	9.06	11.90	7.56[b]	1.64
-	55:45	0-30	73.41	23.41	19.58	3.83	9.07	11.89	7.58[ab]	1.53
		32-58	73.28	23.70	19.69	4.01	9.04	11.83	7.57[ab]	1.58
	75:25	0-30	73.55	23.85	19.91	3.94	9.07	11.93	7.51[b]	1.49
		32-58	74.26	23.81	19.82	4.00	9.06	11.86	7.69[a]	1.61
SEM			0.4539	0.2168	0.1939	0.0547	0.0820	0.1029	0.0454	0.0444
Marginal means										
Mixer	-	-	73.70	23.59	19.71	3.88[b]	9.06	11.85	7.61	1.53
Post-pellet			73.55	23.80	19.79	4.01[a]	9.06	11.91	7.57	1.58
-	55:45	-	73.34	23.56	19.63	3.92	9.06	11.86	7.57	1.56
	75:25		73.91	23.83	19.86	3.97	9.06	11.90	7.60	1.55
-	-	0-30	73.48	23.63	19.75	3.88[b]	9.07	11.91	7.55	1.51[b]
		32-58	73.77	23.75	19.75	4.00[a]	9.05	11.85	7.63	1.60[a]
SEM			0.3209	0.1533	0.1371	0.0387	0.0580	0.0728	0.0321	0.0314
Main effect and interaction probabilities										
LAM			0.7516	0.3294	0.6832	0.0171	0.9997	0.5475	0.3381	0.3053
PF			0.2165	0.2048	0.2405	0.3844	0.9068	0.7048	0.5706	0.8349
Location			0.5209	0.5778	0.9921	0.0323	0.8234	0.5325	0.0836	0.0478
LAM x PF			0.8035	0.8500	0.9391	0.3093	0.0637	0.4953	0.1695	0.4868
LAM x Location			0.2489	0.7925	0.7287	0.8515	0.8198	0.6940	0.0298	0.4463
PF x Location			0.3621	0.4542	0.6086	0.2502	0.9743	0.9712	0.0348	0.4369
LAM x PF x Location			0.7243	0.6421	0.4563	0.4320	0.8316	0.9527	0.9950	0.2309

[a-b]Means within a column not sharing a common superscript differ ($P \leq 0.05$).

[1]Supplemental fat and phytase addition; diets manufactured utilizing mixer LAM had all of the fat (2.44%) and phytase (0.005%) added in the mixer prior to pelleting; diets manufactured utilizing post-pellet LAM had 1% fat added in the mixer prior to pelleting, with the remaining fat (1.44%) and phytase (0.005%) added via post pellet application

[2]PF = pellet to fine ratio; either 55% intact pellets and 45% ground pellets or 75% intact pellets and 25% ground pellets; diets were originally manufactured to contain 75:25 PF, and a portion of this diet was ground to create the 55:45 PF diets.

[3]Location = location in which feed was collected post augering via commercial feed system; feed was augered from the line hopper to the end pan, and feed was collected from 0-30 m (feed hopper to migration fence) and 32-58 m (migration fence to end pan) on a commercial feed line.

[4]Total Breast = pectoralis major plus pectoralis minor.

[5]Breast = pectoralis major

[6]Tender = pectoralis minor

[7]Fat pad = abdominal fat pad

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CHAPTER IV

IMPACT OF FEED SYSTEM AUGERING ON PELLET DISTRIBUTION THROUGHOUT AN ENTIRE COMMERCIAL BROILER HOUSE

Summary

Previous research utilizing one feed line in a commercial poultry house demonstrated that percent pellets steadily decreased and phytase segregated as feed was augered throughout a commercial feed system based upon pellet quality, manufacturing technique, and feed pan location. These factors were found to impact broiler performance and uniformity. The current objective was to investigate variations in pellet distribution as an entire bin of feed is augered throughout a commercial feed system. Four common diets were manufactured at a commercial mill; each diet was delivered to an empty feed bin. Samples were obtained from 3 locations (0, 25, and 50 m) on each of the 6 feed lines (Front, Middle, or Back; Left or Right). Augering time (AT; 9 total) was represented by the 6.5 h period between samples that feed was able to be augered. A feed line x feed pan location interaction demonstrated that percent pellets at 0 m was higher for feed lines on the Right; however, augering to 50 m resulted in a dramatic decrease in percent pellets for the Right Front and Back lines. The main effect of AT decreased percent pellets for AT 7 (43 h); however, a stepwise increase in percent pellets occurred between AT 7 – 9 (43 to 56 h). The highest percent pellets occurred for AT 9 (56 h). These data suggests that variations in mechanical equipment may have affected pellet

attrition and pellet distribution. Additionally, percent pellets available within the house at a particular time can be affected by AT due to pellet and fine segregation within the feed bin.

Keywords: feed quality, feed augering, broiler performance, commercial

Description of Problem

Pelleted diets are predominately fed in the commercial broiler industry due to their many documented benefits; these include decreased feed spillage, reduced nutrient segregation, and ultimately, improved handling characteristics and broiler performance [1-6]. These performance benefits can be improved further as percent pellets increase [5, 7-12]. In general, it is recognized by the poultry industry that increasing pellet quality will improve bird performance; however, feed manufacturers struggle with producing optimum pellet quality due to feed volume requirements and the costs associated with manufacturing them. All aspects of feed quality benefits must be identified so that a value can be associated with an optimal pellet quality to justify the cost of production.

The effects of feed augering on pellet quality and subsequent nutrient segregation is not well documented in literature. Schiedeler [5] was the first to report that nutrient segregation was occurring throughout transportation and feed augering. Recently, a collaborative field study conducted by Mississippi State and West Virginia University determined that percent pellets deteriorated throughout augering feed to the beginning and middle feed pans [13]. At the end of the line, percent pellets increased, and nutrients, especially phytase, segregated based upon manufacturing technique [13]. This study served as an impetus to research conducted by Sellers and cohorts [14], who reported that percent pellets and pellet survival decreased over time and location. Moreover, feed

augering caused phytase to segregate, especially for diets utilizing post-pellet liquid application. The limitations of this research was that only one feed line was utilized and the amount of feed used for each replicate did not fill (only ~681 kg) an entire commercial feed bin (~11,000 kg capacity) [14].

In order to make recommendations to feed manufacturers on optimal pellet quality, it is important to understand how feed augering affects pellet quality as an entire bin of feed is augered throughout a commercial feeding system. This research may help explain the rate at which pellets deteriorate in a whole house and eventually how feed augering affects nutrient segregation. Although data may only depict the events occurring within one house, it may lead feed manufacturers to being one step closer to setting an optimal pellet quality achieved at the mill. This goal may not be common across all mills; however, given an expected pellet quality at point of consumption, it may provide the knowledge necessary to determine a pellet quality that can be economically produced. Hence, the current study's objective was to investigate pellet distribution (by means of percent pellets) over time and location as an entire feed delivery (one full bin of feed) is augered throughout a whole commercial poultry house feed system.

Materials and Methods

Diet Preparations

Four common finisher diets were manufactured at a commercial feed mill [15] and delivered as needed at the commercial broiler house over a ~1.5 week period. Diets were proprietary, but consisted of corn, soybean meal, and meat and bone meal. In addition, diets were formulated to meet or exceed the nutritional requirements of Ross x Ross 708 broilers [16].

The average grind size for each diet was 784 microns. Diets were pelleted using two lines [17, 18] which joined after the horizontal coolers; steam conditioning temperature was 85±1°C. Percent pellets for feed deliveries (n = 4) were 89, 95, 58, and 94%, respectively (average across feed deliveries was 84% pellets); these samples were taken at the mill for each diet as it was augered into the feed truck.

Broiler House and Feed System Specifications

A 16 x 122 m (50 x 400 ft) commercial broiler house located at Mississippi State University was used in the current study. During the experimental period, the broiler house contained approximately 18,000 broilers. The experimental period lasted for four feed deliveries, which began when the birds were six weeks of age and finished when birds were eight weeks of age. The curtain-sided house was tunnel-ventilated; house temperature was regulated by infrared brooders and evaporative cooling. There were eight cup-drinker lines and six total feed lines within the house, and broilers were able to consume feed and water *ad libitum*. Migration fences evenly separated the house into four sections with the halfway point being the feed hoppers. Light-emitting diodes were used in the broiler house, and birds received 20 h of light at 1.5 lux and 4 h of dark during the sampling period.

The broiler house had two feed bins (11,000 kg capacity/bin) [19] that serviced the feeding system [20]; however, only one feed bin was used at a time to serve as the experimental unit. One main screw auger line transported feed into the house, and three downspouts on the main screw auger line fed three feed hoppers. There were six, 58 m long feed lines within the broiler house and each feed hopper supplied two feed lines with feed from the same bin [20]. Each feed line had a total of 76 flood pans (30.5 cm

diameter; 14 spoke grill) [20]. Additionally, one control pan was located on the end of each feed line, and each control pan governed feed augering. The feed line screw auger fit a standard 44 mm diameter feed tube and delivered feed at a rate of 5.9 kg per minute [20].

Feed Augering Sampling Procedure

The feed system sampling diagram for the current experiment is depicted in Figure 1. Each of the six feed lines within the broiler house were used. The feed lines were labeled as the Front Left (FL), Middle Left (ML), and Back Left (BL), as well as the Front Right (FR), Middle Right (MR), and Back Right (BR). Feed lines on the Left were located on the fan end of the broiler house, and feed lines on the Right were located on the evaporative cool pad end of the house. Feed pan sampling locations of 0 (beginning), 25 (middle), and 50 (end) m along each feed line (18 total pans) were used. Each sampling location was blocked off to prevent birds from accessing the feed sample. Feed lines were 58 m long; however, the total sampling distance of 50 m was chosen in order to ensure adequate feed sample volumes were delivered to the last sampling pan.

Each feed delivery occurred when one feed bin was empty; this full bin of feed represented the experimental unit. Sampling times were established based upon the total light hours (20 h) within the house since birds do not eat when the lights are off. Thus, samples were taken every 6.5 light h within the house in effort to provide adequate representation of feed augering effects on an entire feed delivery. For each feed delivery, there were a total of 9 Augering Times (AT; 56 h/feed delivery), which were represented by the 6.5 light h window that feed was collected within the sampling pans post light-feed augering. Post light-feed augering (PLFA) can be defined as the augering that occurred

during light hours between each AT. Augering times occurred at 4 (AT 1), 10.5 (AT 2), 17 (AT 3), 23.5 (AT 4), 30 (AT 5), 36.5 (AT 6), 43 (AT 7), 49.5 (AT 8), and 56 light h (AT 9) PLFA. The sampling timeline (Figure 4.2) for each replicate began by augering the newly filled feed bin into the house (0 h). Two hours after the feed was augered into the feed system, all of the sampling pans were emptied to ensure that the appropriate feed was introduced to the feed lines at the same time. At 4 h, AT 1 samples were obtained. Next, AT 2-9 samples were collected every 6.5 light hours within the house until the feed bin was emptied.

In total, 648 feed samples were obtained across Feed Line, Feed Pan Location, and Augering Time (9 total). Each feed sample was analyzed for percent pellets using a No. 6 American Society for Testing and Materials screen [21].

Statistical Analysis

The experimental period was the total time taken to auger all four feed deliveries (224 h). Each experimental unit of one feed delivery (one feed bin; ~10,500 kg) was augered as part of a randomized complete block with a split-split plot design. Split plot was feed pan location of 0, 25, or 50 m on each of the six feed lines. Split-split plot was augering time (AT 1-9). Treatments were blocked by each of the four feed deliveries (4 replications). Data were analyzed via the GLM procedure in SAS [22]. Mean comparisons were made using Fisher's LSD and significance was established at $P \leq 0.05$.

Results and Discussion

Augering Time Effects

Significance was established for the main effect of AT on percent pellets ($P<0.0001$), but no interaction was found for AT, Feed Line, or Feed Pan Location ($P>0.05$; Table 4.1). Percent pellets demonstrated an ~2.5 percentage point decrease for AT 2 when compared to AT 1; however, AT 3-6 resulted in similar percent pellets in the feed pan PLFA. These data disagree with previous research that demonstrated decreases in percent pellets over time [5, 14]. From AT 6 to 7 a ~5 percentage point decline in percent pellets was observed. Augering Time 7 resulted in the lowest percent pellets (~53% pellets), as compared to all other AT. As feed was augered from AT 7 to 9, percent pellets gradually increased ~13.5 percentage points. These small differences in percent pellets could affect broiler performance [10-12]. In addition, AT 9 demonstrated the highest percentage of pellets in the feed pan (~66% pellets) when compared to all other AT. The stepwise increase from AT 7 to 9 demonstrated that pellets and fines separate as diets are augered out of the feed bin. More specifically, data suggests that fines are released from the bin more readily, while pellets gradually release with greater proportion as the feed bin is emptied (i.e. last AT). However, this is for the observed percent pellets of the tested diets. Feed mill sample percent pellets for feed deliveries (n=4) were 89, 95, 58, and 94%, respectively (average across feed deliveries was 84% pellets). These data may change if diets of other feed qualities were tested.

Interactive Effects of Feed Line and Feed Pan Location

Feed Line and Feed Pan Location significantly interacted for percent pellets ($P<0.0001$; Table 4.2 and Figure 4.3). When diets were augered from the bin to 0 m

(beginning of feed line), the FR, MR, and BR feed lines (average ~63% pellets) demonstrated increased percent pellets (~9% difference) in the feed pan as compared to the FL, ML, and BL feed lines (average ~57.5% pellets). Additionally, the BR feed line resulted in the highest percentage of pellets (64% pellets) at 0 m. The greatest difference in percent pellets (~13%) at 0 m PLFA was demonstrated between the BR and FL feed lines (64 and 56% pellets, respectively). When feed was augered throughout the BL feed line from 0 to 25 m, an ~6 percentage point increase was observed in percent pellets, and the highest percent pellets at 25 m (65% pellets) for any feed line was demonstrated for the BL feed line ($P<0.0001$; Table 4.2 and Figure 4.3). Augering from 0 to 25 m resulted in an ~8 percentage point decrease in percent pellets for the BR feed line, and the lowest percent pellets at 25 m (56% pellets) for any feed line was observed in the BR feed line ($P<0.0001$; Table 4.2 and Figure 4.3).

Percent pellets were similar as feed was augered from 25 to 50 m for the FL, ML, and BL feed lines (average of ~59% pellets). In addition, percent pellets at 50 m for FL, ML, and BL feed lines were similar in percent pellets observed at 0 m for each of those feed lines. However, percent pellets in the FR and BR feed line decreased by ~9.5 and 14 percentage points, respectively, when augered from 25 to 50 m (62.5 to 53 and 56 to 42% pellets, respectively). Moreover, the BR feed line demonstrated the lowest percent pellets (42%) at 50 m when compared to any other feed line or feed pan location; overall, pellets in the BR feed line declined by ~22 percentage points when augered from 0 to 50 m (64 to 42% pellets; $P<0.0001$; Table 4.2 and Figure 4.3).

Data in the current study corroborates with previous field research [5, 13] and partially agrees with replicated research [14]. Results reported by Mississippi State and

West Virginia University demonstrated a decrease in percent pellets when feed was augered from the beginning to middle pan and then percent pellets increased when feed was augered from the middle to end pan [13]. Data in the current experiment demonstrate a significant decrease in percent pellets for feed lines on the Right, especially the FR and BR lines when augered to 50 m. However, the Left feed lines demonstrated less variation in percent pellets across location.

The results for the BR feed line is in full agreement with the research conducted by Sellers and cohorts [14]; it should be noted that this was the same feed line used for both studies, as multiple diets were augered throughout only one feed line for the previous study. In the current study, the BR feed line was the only feed line that demonstrated a similar decrease in percent pellets as noted in the previous study by Sellers and coauthors [14]. Therefore, we speculate that the observed differences in percent pellet could be attributable to the mechanical variability of each feed line. Although the mechanism between feed augering and pellet deterioration is not documented in previous literature, it is proposed that variations in auger motors can affect the shear force and translational shear velocity [23] of the screw auger when feed comes in contact with the feed line. If velocity and force are greater, there is more potential for pellets to experience attrition due to increased shearing force with the auger.

Overview

Pelleting is a complex process that has many interactive variables, including diet formulation, production rate, conditioning, particle size, die specifications, and cooling/drying [24-30]. These factors affect feed form, nutrient availability, and ultimately, bird performance [26, 29-30]. As expected, data observed in the current study

confirms that feed quality in terms of percent pellets is further affected by feed augering (Table 4.2) similarly to what was reported previously [5, 13-14].

Percent pellets sampled at locations across the house available for broiler consumption differed across Feed Line and Feed Pan Location. We speculate that feed augering may also vary between different feed systems and may not be consistent with the current results due to speculated variations in equipment. However, results of the current study does provide much needed data describing pellet distribution as it occurred in the commercial house sampled. These data should be taken into consideration by feed manufacturers when determining a target pellet quality in order to maximize growth and profit potential.

Furthermore, the main effect AT demonstrates that pellets and fines separate within the feed bin over time (Table 4.1). The separation of pellets and fines have also demonstrated nutrient segregation [5, 13-14]. Moreover, previous research suggests that broiler BWG and BW CV can be affected by percent pellets because of differences in pellet quality and nutrient segregation noted across Feed Line and Feed Pan Location [31]. As nutrients segregate, it is possible that broilers do not receive the adequate level of one of more nutrients required to maximize performance and ultimately profit for the company. Data demonstrates that AT impacts percent pellets available for consumption at a given time and we speculate, based on previous research [14], the nutrients levels therein. Future research should determine if the changes observed in percent pellets is based on beginning feed quality, equipment, and/or birds. Multiple broiler houses may provide a better representation and broader understanding of the events occurring during

feed augering; thus, allow us to become closer to determining an optimal pellet quality for feed manufacturers to produce.

Conclusions and Applications

1. Percent pellets (~84% pellets upon delivery) were affected by AT of feed from the feed bin, with the lowest for AT 7 (53% pellets) and highest for AT 9 (66% pellets). These data suggest that fines are released from the bin more readily, while pellets gradually release with greater proportion as the feed bin is emptied (i.e. last AT).

2. Pellet distribution was affected by Feed Line and Feed Pan Location. Data in the current study demonstrated a 22 percentage point decrease in pellets when the BR feed line was augered from 0-50 m. Percent pellets in the BL feed line increased by 6 percentage points when augered from 0-25 m and decreased by 6 percentage points when augered from 25-50 m. These data suggest that feed augering should be considered when choosing an optimal pellet quality to be created at a commercial feed mill.

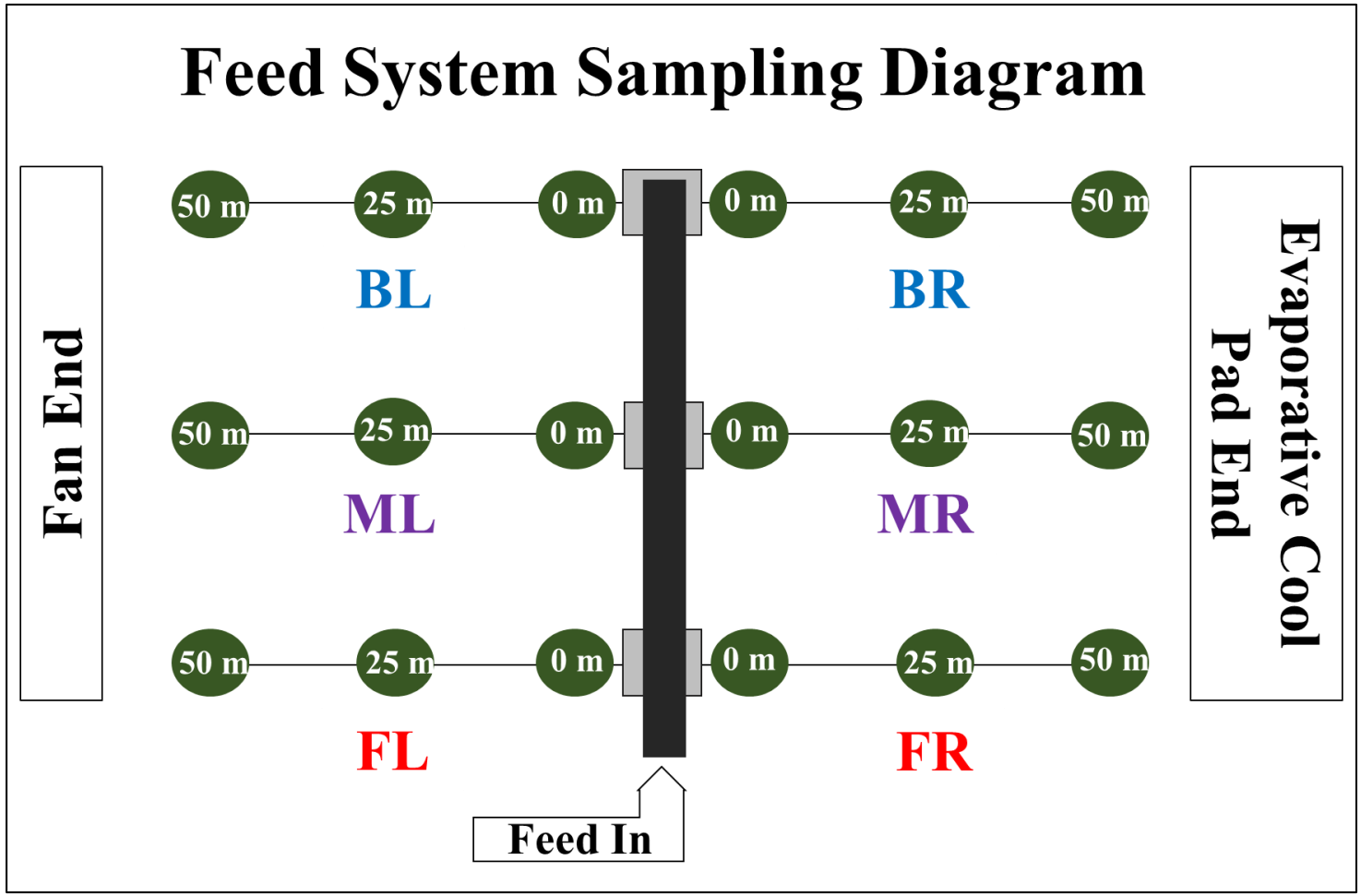

Figure 4.1 Feed system sampling diagram of each feed line[1] and feed pan location[2]

[1]Feed Line = feed line used within the commercial broiler house. FR = Front Right, MR = Middle Right, BR = Back Right, FL = Front Right, ML = Middle Left, and BL = Back Left. Right feed lines were on the cool cell side of the house, and Left feed lines were on the fan end of the house. A total of 3 hoppers serviced 6 feed lines. As feed was augered into the house, the first hopper fed the Front L and R feed lines, the middle hopper fed the Middle L and R feed lines, and the last hopper fed the Back L and R feed lines
[2]Location = Feed Pan Location. Sampling locations of 0, 25, and 50 m were used to determine feed quality at the beginning, middle, and end of each feed line as diets were augered throughout the house

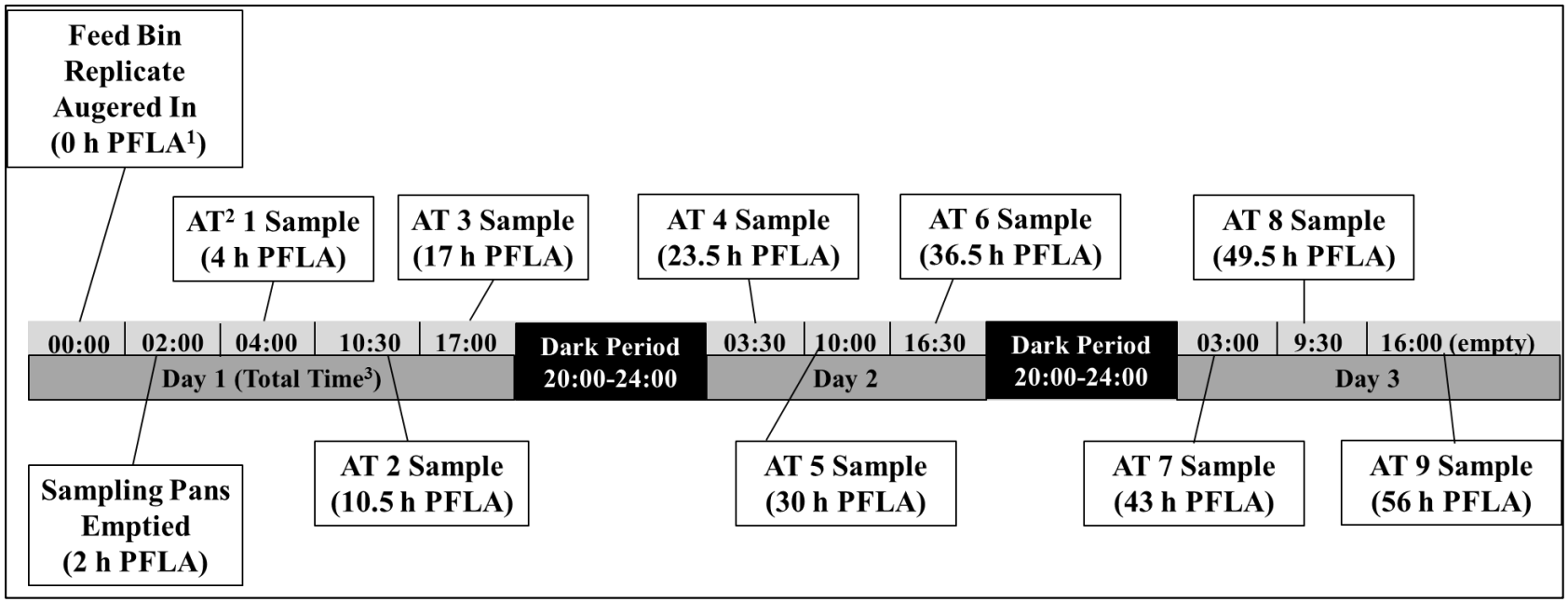

Figure 4.2 Feed augering sampling timeline

[1]PFLA = Post light-feed augering; augering that occurred during light hours (20 total light hours; 4 dark) between each AT
[2]AT = Augering Time; represented by the 6.5 light hour window that feed was collected within sampling pans post light-feed augering until the bin was emptied. AT were as follows: AT 1 = 4 h; AT 2 = 10.5 h; AT 3 = 17 h; AT 4 = 23.5 h; AT 5 = 30 h; AT 6 = 36.5 h; AT 7 = 43 h; AT 8 = 49.5 h; AT 9 = 56 h
[3]Total time = total number of hours during feed augering procedure of each replicate; total times listed are example times

Table 4.1 The effect of augering time on percent pellets

Augering Time[1]	Percent Pellets[2] (%)
1	59.88[bc]
2	57.34[d]
3	59.20[bcd]
4	60.03[b]
5	57.96[bcd]
6	57.56[cd]
7	52.64[e]
8	57.74[cd]
9	66.05[a]
Main effect and interaction probabilities	
AT	<0.0001
Line[3] x AT	0.7975
Location[4] x AT	0.1776
Line x Location x AT	1.000
SEM	0.8545

[a-d]Means within a column not sharing a common superscript differ ($P \leq 0.05$)

[1]Augering Time (AT) = represented by the 6.5 light hour window that feed was collected within sampling pans post light-feed augering until the bin was emptied. AT were as follows: AT 1 = 4 h; AT 2 = 10.5 h; AT 3 = 17 h; AT 4 = 23.5 h; AT 5 = 30 h; AT 6 = 36.5 h; AT 7 = 43 h; AT 8 = 49.5 h; AT 9 = 56 h

[2]Percent pellets = (intact pellet sample weight/total sample weight)*100%. The total sample was initially weighed and subsequently sifted using a No. 6 American Society for Testing and Materials screen (metric equivalent = 3.35 mm) to separate intact pellets from fines; the pellet sample was then weighed and percent pellets was calculated

[3]Line = Feed Line used within the commercial broiler house. Right feed lines were on the cool cell side of the house, and Left feed lines were on the fan end of the house. A total of 3 hoppers serviced 6 feed lines. As feed was augered into the house, the first hopper fed the Front L and R feed lines, the middle hopper fed the Middle L and R feed lines, and the last hopper fed the Back L and R feed lines

[4]Location = Feed Pan Location. Sampling locations of 0, 25, and 50 m were used to determine feed quality at the beginning, middle, and end of each feed line as diets were augered throughout the house

Table 4.2 Effects of feed line and feed pan location on percent pellets

Line[1]	Location[2] (m)	Percent Pellets[3] (%)
Front (R)	**0**	62.18^{bcd}
	25	62.57^{abc}
	50	53.00^{h}
Middle (R)	**0**	62.71^{abc}
	25	59.66^{ef}
	50	59.22^{ef}
Back (R)	**0**	64.10^{ab}
	25	55.89^{g}
	50	42.25^{i}
Front (L)	**0**	56.34^{g}
	25	59.90^{def}
	50	57.65^{fg}
Middle (L)	**0**	57.41^{fg}
	25	60.90^{cde}
	50	59.06^{ef}
Back (L)	**0**	59.25^{ef}
	25	64.98^{a}
	50	59.72^{def}
SEM		0.8715
Marginal means		
Front (R)	-	59.25
Middle (R)		60.53
Back (R)		54.08
Front (L)		57.96
Middle (L)		59.12
Back (L)		61.32
SEM		0.4794
-	**0**	60.33
	25	60.65
	50	55.15
SEM		0.3558
Main effect and interaction probabilities		
Line		<0.0001
Location		<0.0001
Line x Location		<0.0001

[a-i]Means within a column not sharing a common superscript differ ($P \leq 0.05$)

[1]Line = Feed Line used within the commercial broiler house. Right feed lines were on the cool cell side of the house, and Left feed lines were on the fan end of the house. A total of 3 hoppers serviced 6 feed lines. As feed was augered into the house, the first hopper fed the Front L and R feed lines, the middle hopper fed the Middle L and R feed lines, and the last hopper fed the Back L and R feed lines

[2]Location = Feed Pan Location. Sampling locations of 0, 25, and 50 m were used to determine feed quality at the beginning, middle, and end of each feed line as diets were augered throughout the house

[3]Percent pellets = (intact pellet sample weight/total sample weight)*100%. The total sample was initially weighed and subsequently sifted using a No. 6 American Society for Testing and Materials screen (metric equivalent = 3.35 mm) to separate intact pellets from fines; the pellet sample was then weighed and percent pellets was calculated

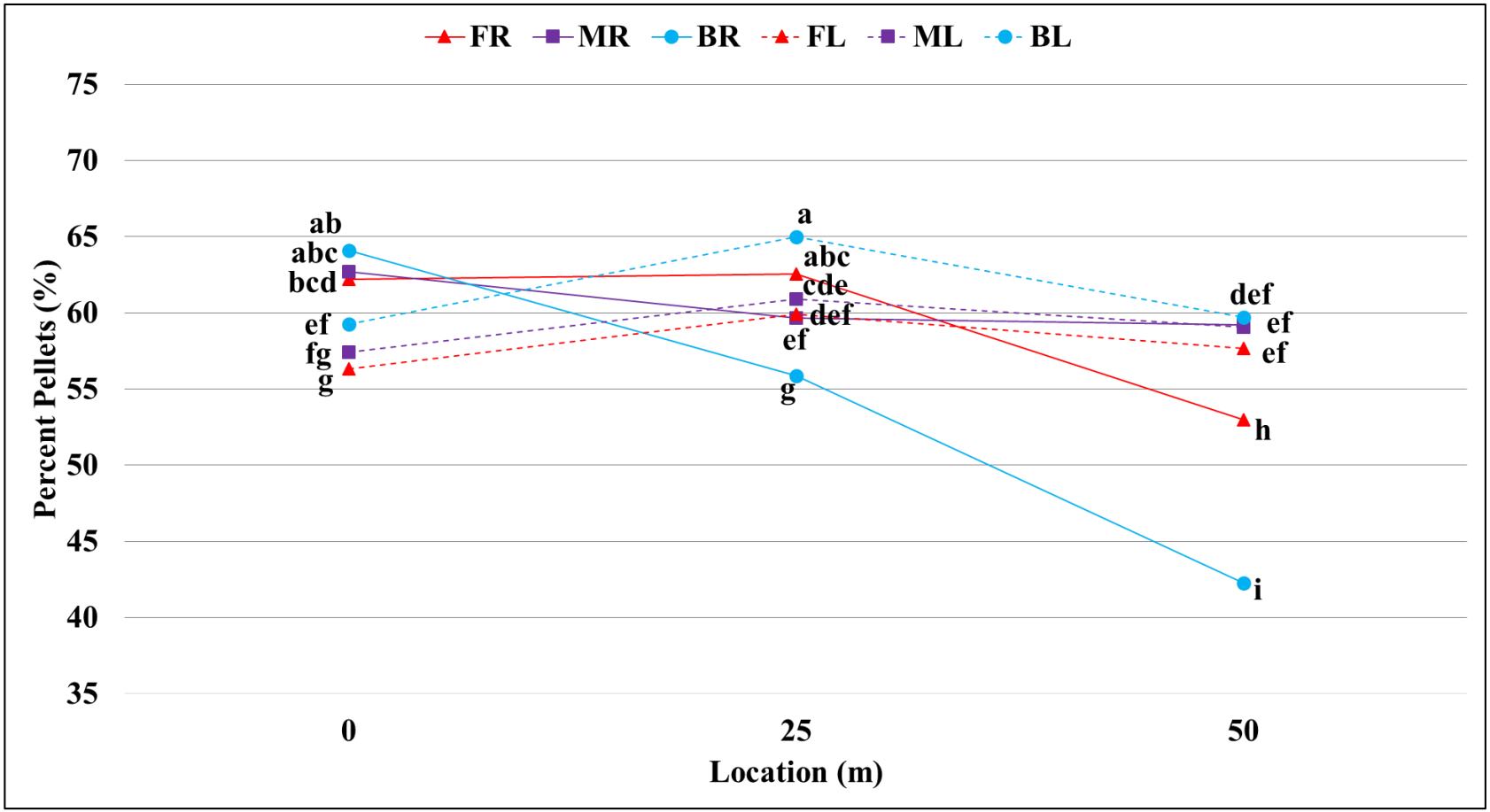

Figure 4.3 Interactive effects* of feed line[1] and feed pan location[2] on percent pellets[3]

*P<0.0001; SEM=0.8715

[1]Feed Line = feed line used within the commercial broiler house. FR = Front Right, MR = Middle Right, BR = Back Right, FL = Front Right, ML = Middle Left, and BL = Back Left. Right feed lines were on the cool cell side of the house, and Left feed lines were on the fan end of the house. A total of 3 hoppers serviced 6 feed lines. As feed was augered into the house, the first hopper fed the Front L and R feed lines, the middle hopper fed the Middle L and R feed lines, and the last hopper fed the Back L and R feed lines

[2]Location = Feed Pan Location. Sampling locations of 0, 25, and 50 m were used to determine feed quality at the beginning, middle, and end of each feed line as diets were augered throughout the house

[3]Percent pellets = (intact pellet sample weight/total sample weight)*100%. The total sample was initially weighed and subsequently sifted using a No. 6 American Society for Testing and Materials screen (metric equivalent = 3.35 mm) to separate intact pellets from fines; the pellet sample was then weighed and percent pellets was calculated

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