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Evaluation of Cobb MV × Cobb 500 broiler response to various nutrient regimens to maximize performance and economics

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By

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Evaluation of Cobb MV × Cobb 500 broiler response to various nutrient regimens to maximize performance and economics

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To maximize the economics of a new commercial broiler cross, research on its nutritional specifications is necessary. Study 1 investigated the effects of feeding four amino acid densities (AAD) on performance and yield of Cobb MV × Cobb 500 broilers at d 33 and 36. Data demonstrated a stepwise decrease in feed conversion ratio (FCR) as AAD level increased. Improvements in performance, processing, and economic return were observed when feeding higher AAD levels. Study 2 estimated the digestible lysine (dLys) requirements of Cobb MV × Cobb 500 broilers from d 0-14 and evaluated the impact of varying starter dLys levels on their performance, processing, and economic return during a 42 d grow-out. Data suggested that d 0-14 dLys requirements varied based on broiler response and statistical model. Improvements in overall performance was observed when feeding ≥1.12% dLys during the starter phase. The greatest economic return was associated with feeding starter dLys of 1.20%. Due to the potential interaction between AA and apparent metabolizable energy (AME), Study 3 examined the response of Cobb MV × Cobb 500 to varying dLys and AME levels from d 0-14 on d 0-42 performance and processing. A dLys × AME interaction was observed for d 0-28 FCR and for dLys and

AME for early performance parameters. However, this significance was lost by the end of the study. Due to the variation in broiler response to feeding strategies at different ages, Study 4 evaluated the impact of varying dLys and AME levels from d 14-28 on performance and processing of 42-day old Cobb MV × Cobb 500 broilers. Data demonstrated significant dLys × AME interactions for d 14-28 and 14-35 FCR, as well as significances for main effect of dLys and AME for performance and processing (d 42). Feeding grower diets formulated to 1.18% dLys + 3028 kcal/kg AME was the most profitable diet. Overall, this research demonstrates that higher AAD improved broiler performance, especially ≥1.12% starter dLys. Varying dLys and AME during the starter phase did not affect performance at d 42; however, it did when this regimen was exercised during the grower phase.

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CHAPTER I

LITERATURE REVIEW

Poultry Production in the U.S.

The consumption of poultry products in the U.S. has continuously increased due to their affordable price and great nutritional value. Poultry meat is the second most consumed meat in the world [1]. It has been the most consumed meat in U.S. over the past couple of decades, with a per capita consumption of poultry products reaching 109.6 lbs in 2018, of which 92.1 lbs was broiler meat [2]. Therefore, poultry is one of the largest agricultural commodities in the U.S., producing ~$46.3 billion of sellable products in 2018 [3]. The value of broiler production in 2018 was $31.8 billion (approximately 69% of total poultry production value), with 9 billion slaughtered broilers and approximately 56 billion pounds produced [3]. In 2018, the direct economic impact of the poultry and egg industry in the U.S. was reported at $171.1 billion, and it was responsible for 509,820 direct jobs [4]. Furthermore, broiler production is one of the most important sectors in the U.S. agricultural economy, especially for the southeast region, which contains the top five broiler producing states (Georgia, Alabama, Arkansas, North Carolina, and Mississippi) [3]. Since the research projects to be discussed later in this dissertation, were conducted in Mississippi, the next section of this literature review will be focused on Mississippi poultry production.

Mississippi Poultry Production

Poultry is the most important agricultural commodity in Mississippi, accounting for ~$3 billion value in 2018 (with $2.7 being associated with broilers). This corresponded to approximately 39% of the total value of Mississippi's agriculture production [5]. In addition, Mississippi is home to six of the largest broiler companies in the U.S.: Tyson Foods Inc., Sanderson Farms Inc., Peco Foods Inc., Wayne Farms LLC, Koch Foods, and MarJac. Cal-Maine Foods, the largest egg company, is also locating in this state. In 2018, a total of 747 million broilers were produced and 1,430 farms were recorded; the main broiler producing counties in Mississippi were Scott, Smith, Jones, Simpson, Leake, Newton, and Wayne [6].

Advancements in Poultry Production

The world population is estimated to reach 9.8 billion by 2050 [7] and with the increase in number of people, there are concerns about producing adequate food to supply the needs of this growing population [8]. Therefore, one of the greatest challenges faced by the agricultural sector has been to improve the efficiency of food production. To improve poultry production, several advancements in different areas of this industry have been made, such as vaccination, housing, nutritional requirements, and genetic selection [9]. These advancements will be discussed within the next few sections of this literature review, with emphasis on genetics and nutrition due to the interest of the author.

Management

In a period of 50 years, the methods of raising poultry has changed more than in any other animal production. Poultry has become the most intensive of all sectors of animal farming [10]. Investigations on the environmental conditions and physiological needs of poultry demonstrate the importance of controlling light, temperature, and ventilation programs to improve poultry production. For example, poor ventilation systems can lead to high levels of ammonia in the chicken house, and this was previously reported to decrease the body weight gain of chicks by 20% at d 7 [11]. Biosecurity programs and several methods of vaccination, such as in-ovo vaccination (in the U.S.), have been used for the disease prevention and improve poultry health. Different housing systems and waste management techniques have been evaluated to promote animal welfare and sustainability in the poultry industry [12, 13]. The main goal of management is to provide all the conditions needed by the birds for optimum performance [14].

Genetics

In 1930, broiler production had its beginning as a commercial business in the U.S., in which pure Barred Plymouth Rocks were the first broiler [15]. Around 12 years later, 97% of the commercial broilers were from the crossing of the Barred Plymouth Rock male and the Rhode Island Red or New Hampshire female [15]. Over the years, poultry scientists have done extensive research on broiler breeding problems, in which the most studied traits are growth rate, conformation, feed efficiency, and feather color [15]. Genetics is one of the main advancement areas in poultry production accredited with the majority of performance improvements (85-90%), while advancements in nutrition have contributed by 10-15% of these improvements [16]. The driving force behind these nutritional advances was the need to sustain/optimize the improvements in genetics [16]. Amazingly, the efficiency of production has been continuously improved by 2-3% per year due to the genetic selection for growth, feed efficiency, meat yield and composition, reproduction, welfare, and health [9].

Modern Commercial Broilers

Due to advancements in several areas of the poultry industry, the modern commercial broiler is one of the most efficient protein sources, resulting in a huge difference between the modern broiler and past genotypes. It was previously reported that in 1925, a broiler required 112 days to reach a target weight of 2.5 kg; whereas a commercial broiler of today can reach the same weight in ~30 days [17]. As previously mentioned, literature has stated that genetic selection has the greatest impact on improving broiler growth rate (85-90%), while the rest (10-15%) is associated with nutrition advances [18-20]. In addition, this selection has improved meat yields. In 1962, only 2% of broilers were sold as further processed meat products, 15% as cut or parts, and 82% as whole carcass [21]; in 2005, 46% were sold as further processed products, 43% as cut or parts, and 11% as whole carcass [21].

Cobb MV × Cobb 500

In 2017, as a result of the continuous search for improvements in existing broiler crosses to meet consumer demand for protein sources and reduce production cost, Cobb-Vantress [22] introduced to the market a new broiler breeder product. This product, the Cobb MV male, was developed to further improve the male line in terms of FCR and meat yield at the broiler level, while maintaining reproductive traits, such as hatchability and fertility, from the previous Cobb MX male [23]. The Cobb 500 female line is reported to have an efficient growth on least cost diets, low FCR, and hatchability of 85.6% [24].

Breeding these two lines has led to the production of a new commercial broiler cross, Cobb MV × Cobb 500 [23], which is reported to be robust and adaptable to several weights, environments, and nutritional programs [23]. To fully optimize the performance and economics of this new commercial broiler cross, research is needed to evaluate its response to different nutritional specifications.

Nutrition and Diet Formulation

The key for efficient growth and performance for any livestock animal is providing adequate nutrition, since the deficiency of any nutrient can cause lethargic growth or disease, whereas feeding birds with an excess nutrient diets can cause increased cost, and even toxicity/death. Feed costs make up 60-70% of the total broiler production costs [25], and poultry nutritionists usually formulate least-cost diets to avoid profit loss, while providing diets that meet nutrient requirements that yield the production goals [25]. For example, diets are currently formulated based on the digestible amino acid (AA) basis instead of total AA basis (as previously done), resulting in a more accurate, cost effective method to meet the bird's needs [26].

Another factor with U.S. poultry diets is that they are mainly comprised of corn and soybean meal. However, some factors (e.g. nutrient availability and requirement, ingredient prices, production goals, bird age, and feed consumption) can alter the inclusion of corn and soybean meal in the diets and can require the addition of other feedstuffs [25]. For example, by-products from ethanol production and meat processing, like corn distillers dried grains with solubles and meat & bone meal, have been used to reduce feed costs. However, the nutrient quality of these by-products can vary.

Essential nutrients are sourced from several ingredients such as cereal grains, oilseed meals, and by-products [27]. Among the essential nutrient classes for poultry, carbohydrates, lipids, and proteins are important in providing energy that is required for body maintenance and production. Corn, animal fat or vegetable oil are commonly used in the U.S. to meet energy requirements [27]. In addition, AA are the building blocks of protein and essential for muscle development and other metabolic processes. The most common oilseed meal used to provide AA is soybean meal. Synthetic AA, meat & bone meal, and other animal by-products are often added to the diets in order to meet the bird's AA requirement [27]. Making up less than 5% of the diet, vitamins and minerals are known as micro-ingredients and are added via premix to prevent deficiencies and provide all the essential vitamins and minerals for proper growth and development of poultry [25]. All these nutrients will be discussed later in this literature review.

Nutrients

Nutrients can be classified into six classes, water, carbohydrates, fats, proteins, vitamins, and minerals [28]. Among these nutrient classes, water is one of the most important nutrients. Approximately 70% of the chicken's body is water [29], and animals can survive several weeks without food but only a few days without water [30]. In addition, water is essential in the digestion process, for instance, softening feed and carrying it through the gastrointestinal tract. Additionally, water is the main component (~90%) of the blood that is responsible for distributing nutrients, gases, and other substances inside of the animal's body [30].

Carbohydrates are organic compounds of carbon, hydrogen, and oxygen molecules, which are responsible for providing energy that plays an essential role in proper growth and basal functions such as cellular respiration, production of hormones, and other functions [31]. Corn is the main energy source in poultry diets in the U.S. Carbohydrates can be found in plant sources in the form of starch and non-starch polysaccharides (NSP), such as cellulose, arabinoxylans, and β-glucans, which are broken down into glucose units by enzymes. Glucose units are absorbed by the animal and stored as glycogen, mainly in the muscles and liver [32].

Proteins are organic compounds made of amino acids (AA) which are nitrogen-containing molecules used in the construction of muscles, nerves, skin, feathers, and among others [30]. Amino acids can be classified into essential and non-essential AA (EAA and NEAA, respectively), in which the first group is not produced or is produced in insufficient amount by the bird's body and the second one is synthesized by the bird. Therefore, EAA need to be supplemented in poultry diets and determining the exact amount of EAA required by the bird is essential for its proper muscle accretion [33]. In the U.S., protein can be provided from vegetable (soybean meal) or animal (meat and bone meal) sources, with the supplementation of crystalline AA to the diet to meet the EAA requirements [27]. To reduce cost and avoid excess of AA excretion, poultry diets have been formulated based on digestible AA [27].

Fats or lipids are the nutrient class that provide the most dense source of energy, as well as essential fatty acids to the animal; they also facilitate the absorption of fat-soluble vitamins [34]. Lipids are the most efficient energy source; 1 gram of carbohydrate or proteins provides 4 calories, while 1 gram of fats provides 9 calories [35]. Triglycerides are a type of lipid that are composed of a molecule of glycerol and three fatty acids (FA), in which FA are responsible for the production of hormones and cell-membrane integrity [30].

Vitamins are organic compounds that play a role in body metabolism, growth, and reproduction [30]. They are classified into two groups, fat- and water-soluble, in which the first group is comprised of vitamins A, D, E, and K, while the second group includes vitamin C and the B complex (vitamin B_{12}, biotin, folacin, niacin, pantothenic acid, pyridoxine, riboflavin, and thiamin) [30]. Vitamin A is essential for the proper growth of epithelial tissues and the reproductive system. Vitamin D_3 is needed for bone and eggshell development [30]. Vitamin K is crucial for blood-clot formation. The vitamin C and B complex are responsible for many biochemical processes, such as collagen synthesis and energy metabolism, respectively [30].

The last class of nutrients is minerals, which are inorganic compounds required for several important functions, including bone development, enzyme activation, and muscle contraction. They are divided into macro- and microminerals; in which macro-minerals are required at higher levels and microminerals in lower amounts. The first group of minerals includes calcium, phosphorus, chlorine, sodium, potassium, and magnesium; the second group, also known as trace minerals, are composed of iron, selenium, zinc, copper, iodine, and manganese [30].

Protein Metabolism

Protein metabolism consists of the chemical process to break down (catabolism) proteins and synthesize (anabolism) proteins and AA. The catabolism of proteins is initiated in the stomach by HCl and the enzyme pepsin, where proteins are broken down into AA [36]. Some hormones and proenzymes (e.g. secretin, trypsinogen, and chymotrypsinogen) secreted by the small intestine and pancreas, respectively, also aid in the digestive process. Enterokinase, an enzyme produced by the cells of the duodenum, is responsible for the conversion of trypsinogen into trypsin, which activates chymotrypsin [36]. These enzymes are responsible for releasing the AA that comprised the original protein so that they can be absorbed by the cells lining the small intestines, and ultimately transported into the bloodstream for distribution throughout the body [36].

Amino acids, when in excess, are processed and stored as glucose or ketones in the body. This process produces a nitrogenous waste (ammonia) which is toxic and needs to be converted into urea (mammals) or uric acid (birds) and then excreted by the body. This process is known as the Urea cycle and occurs in the liver and kidneys [36]. In times of starvation, AA can be converted into metabolic intermediates of the Krebs cycle, like pyruvate, acetyl CoA, acetoacyl CoA, oxaloacetate, and α-ketoglutarate, via the transamination process and can be used as a source of energy [36].

Energy Metabolism

Energy metabolism is defined as the conversion of chemicals (e.g. glucose, fatty acids, and AA) or physical energy (from sunlight) into biological energy, which can occur via several processes, e.g. fermentation, cellular respiration, and photosynthesis [37]. Adenosine triphosphate (ATP) is a nucleotide molecule that carries the energy essential for life, playing an important role in basal functions, body metabolism, production of enzymes and hormones, body temperature regulation, etc. [31]. Plants and other organisms, such as cyanobacteria and algae, produce some of their nutrients from a process called photosynthesis, which uses sunlight to convert CO_2 and water into sugar molecules (chemical energy) and O_2. However, animals cannot photosynthesize, and they need to get their energy by eating plants, other animals, or both [38].

Animals raised to produce commodities depend on their diet composition and their efficiency to utilize all dietary nutrients provided to maintain their vital functions and produce the desired products (i.e. egg, milk, meat, etc.). As previously mentioned, the nutrients that deliver energy to the animals are carbohydrates, fats, and proteins [39]. There are two forms of energy storage in animals, which are glycogen and fat. Glycogen, along with cellulose and starch, are the major forms of glucose polymers, in which glycogen is a large α-1,4-glucose polymer with α-1,6-branches every 10 residues. This polymer is produced by animals and bacteria and it can be found in several tissues, mainly in the muscles and liver [32]. Plants use starch as their energy storage form, which is a large α-1,4-glucose polymer with α-1,6-glycosidic bonds. The main structural difference between glycogen and starch is the frequency of branching, in which glycogen contains more branches than starch [32].

Glycogen is an efficient energy storage form since glucose can be readily added and removed from it. This polymer is synthesized from glucose-6-phosphate by three reactions, phosphoglucomutase, UDP-glucose pyrophosphorylase, and glycogen synthase, which the last one is the main control for glycogen synthesis in animals [40]. Furthermore, glycogen synthesis and its mobilization (glycogen phosphorylase) are regulated by hormones, such as insulin, glucagon, cortisol, and epinephrine. During high activity level, glucose can be converted into lactate to produce energy in absence of oxygen; this process is known as the Cori cycle or lactic acid cycle [41].

Another type of energy storage is fat in adipose tissue; as previously mentioned, it is the most efficient form of energy. It also helps in the regulation of body temperature and acts as source of hormones [39, 42]. However, fat cannot be mobilized as quick as glycogen in skeletal muscles, since energy is required for initiation of β-oxidation of fatty acids, and oxygen is required for energy production [40].

Feeding Strategies

In today's poultry industry, nutritionists are striving to find the most feasible production system, by evaluating different management and feeding programs. Due to the high competitiveness of this industry and the large volume produced, every small improvement could lead to huge savings for producers [43, 44].

To reach different markets, commercial broiler production systems can be as short as 4 weeks of age for fast-food markets and up to 9 weeks of age for further processing/cut-up markets [43]. In an effort to maximize poultry production, the grow-out period is divided into small periods or feeding phases, where birds are provided diets that meet their nutritional needs during a certain age [45]. This is important since age is one of the factors that affects the nutritional requirements of a bird. However, there is a limitation on the number of feeding phases due to the impracticality of producing multiple commercial diets; therefore, most companies use no more than 3-4 different diets for broilers [45].

In 1994, the National Research Council (NRC) published the latest edition of the nutrient requirements of poultry, in which the grow-out period is divided into three feeding phases: starter (0-3 weeks of age), grower (3-6 weeks of age), and finisher (6-8 weeks of age). However, these phases are too broad and do not follow what is used by in current commercial poultry production [43, 44]. Besides NRC (1994), there are various recommendations for formulating broiler diets, such as Brazilian tables and recommendations by U.S. primary breeder companies, in which recommended nutrient levels and number of phases vary. For example, the following feeding phases are recommended in the Cobb 500 guidelines: starter (0-10 days of age), grower (11-22 days of age), finisher 1 (23-42 days of age), and finisher 2 ($\geq$ 43 days of age) [46]. These feeding phases will be further discussed in the next few sections of this literature review.

Starter

Literature has shown that the time of feeding diets can significantly affect growth, broiler uniformity, and economic return [43, 44, 47-54]. The period between the late stage of embryogenesis and early post-hatch is marked by the occurrence of major changes in the gastrointestinal morphology of a bird. This is because they need to be able to consume nutrients after hatching, as there is a shift from receiving nutrients from the yolk, rich in lipids, to a solid diet with carbohydrates and proteins [55].

A strong effect of age was previously observed on the efficiency of protein retention and deposition [56], in which the efficiency during the first seven days of age was 68% and approximately 23% at 42 days of age [56]. Therefore, the early post-hatch period is an important phase, as inadequate early nutrition may negatively affect muscle deposition in later phases [57]. Also, literature has reported that cell proliferation and digestive tract growth occur early life. Therefore, it is essential to provide proper nutrients to broilers during this grow-out period.

A previous study found that post-hatch nutrition could affect final broiler performance [58]. More studies on post-hatch nutrition have been conducted due to the strong positive correlation observed between early and end of the production body weight

[59, 60]. If improvements associated with starter period are observed at the end of the grow-out period, early feeding strategies can be beneficial to the commercial industry due to the small volume of feed consumed during this phase. For example, feeding high AAD may be economically interesting due to the low percentage of the total feed costs of a broiler production during the starter period [61].

Grower

Literature has reported a gradual decrease in AA requirements throughout the grow-out period [43]. A clear response of broilers to increasing AA density was previously observed in the grower phase [62]. Previous research has also demonstrated that feeding high AAD through 28 d should be economically feasible due the low feed consumption in the beginning of growout in comparison to the later phases [63]. The AME requirements of broilers during the grower period may vary with respect to the growth rate [62]. Also, a previous study evaluating varying levels of AME from 22-35 d of age found that feed intake and FCR were affected by AME of diet; there was a linear decrease in feed consumption and feed conversion ratio as AME of the diet increased [64].

Finisher

Feeding AAD at suboptimal levels or in excess can be expensive, especially if the final product is for the debone market, because approximately 70% of total feed intake occurs from 35 to 63 d of age [63]. Therefore, it is possible to have adverse effects in growth performance and processing yield in the finisher phase due to the restriction of lysine (Lys), which is an AA important for muscle synthesis and it is present in a high percentage in poultry meat [63]. Additionally, previous literature has reported an improvement in FCR when feeding a higher energy level during the finisher phase [65-67]. Due to the data demonstrating the impact of AAD and AME on broiler performance, this dissertation will explore these formulation strategies. In the next section of this literature review, the philosophy of formulation and various strategies will be explored in more detail.

Formulation Strategies

When formulating poultry diets, one of the main concerns is the level of AA; as previously mentioned, they are building blocks of several body tissues and metabolic functions [68]. Since the feed ingredients that provide protein and AA are one of the most expensive components in poultry diets, it is important to feed adequate amount of these nutrients for a proper growth, as well as reduction of diet cost [69].

The supplementation of synthetic AA is commonly performed to obtain diets with an ideal AA profile [70]. The ideal protein concept aims to optimize protein utilization by providing the bird with all the AA, without deficiency or excess; resulting in a precise ratio of AA which would also reduce nitrogen excretion into the environment. This concept uses lysine (Lys) as a reference AA and the requirement for all other AA is expressed relative to Lys; in which the ideal ratio is not influenced by factors that affect AA requirements [71].

One factor to consider when formulating diets is the use of digestible AA values instead of the total values. Some benefits previously reported of formulating on digestible AA basis are the reduction of safety margins, a better uniformity of final product, and a more accurate performance prediction [33]. Digestible AA is defined as the amount of AA that is remaining after subtracting the amount of AA excreted in the feces or ileal fluids from the total AA ingested [72]. However, it is important to mention that not all digested AA are available for protein synthesis [73]. In some cases, AA are absorbed in a form not appropriate for animal utilization [74].

Another concern when formulating diets is the energy level, provided by carbohydrates, proteins, and lipids. Noteworthy, the feed ingredients that supply energy to the birds are one of the main contributors for total feed costs [75]. In addition, dietary energy is essential for many metabolic processes [64]. Previous literature reported a reduction in feed consumption when feeding higher energy density diets [76], suggesting that broilers can control their feed consumption in order to meet their energy requirements [77].

An increase in fat deposition was found when feeding increased energy levels and this is likely due to the link between dietary energy and the activity of enzymes that are responsible for the production of fatty acids from acetyl-CoA in the bird's liver [78]. Fatty acid synthase (FAS) is one of the enzymes that plays an important role in the hepatic *de novo* lipogenesis, as its activity regulates the bird's ability to produce deposits of fatty acids [79].

Other factors to consider include the protein and energy levels in the diet. It was previously reported that feeding a low energy:protein ratio resulted in broiler carcasses with reduced fat content [80, 81]. Whereas diets with high energy:protein ratio increased *in-vitro* lipogenesis rate [82] and hepatic lipid synthesis [83]. Conversely, a previous study observed increased protein content and decreased fat content with increasing energy and protein levels [84].

Differences in broiler responses to varying nutrient densities may be due to the influence of several factors (such as strain) [85]. Previous literature found a variation in responses to dietary Lys levels among different strains [86-90]. This could be due to the differences in muscle development and feed consumption. For example, a high-yielding strain has more breast muscle total RNA and total DNA content than a low-yielding strain, and the number of nuclei or total DNA has been reported to be associated with muscle development [91, 92].

Determining Requirements

The requirement of a specific nutrient is the amount of nutrient required for proper performance [27]. Diets should contain all nutrients at the required levels, since deficient or excessive levels of any nutrient can be detrimental to the animal, resulting in reduced performance [93]. However, the biggest challenge in determining nutrient requirements is their variation due to several factors, which can be bird-related factors (such as genetics, sex, and age) or external factors (i.e. stress and environmental conditions) [94].

Nutritionists know that feeding each nutrient at an optimum concentration will improve bird performance; it is also known that feeding too low or high of a nutritent will decrease performance [95]. Currently, guidelines with nutritional recommendations for modern crosses are provided by the primary breeder companies, containing more accurate recommended nutrient levels than those provided by the NRC (1994) [94].

Determining the AA requirements of a bird is essential due to their economic importance, because AA are needed for proper muscle growth [33] and they are one the most expensive components in the poultry diet [94]. A common method used to determine AA requirements is the ideal protein concept, where the Lys requirements for a specific strain and environmental conditions are stablished and then all the other AA are expressed as percentage of Lys [96]. There are several reasons why Lys was chosen as the reference AA. For one, Lys is the second-limiting AA for poultry, it is used only for protein growth and maintenance, and it has no metabolic interactions with other AA [71]. Therefore, it is important to accurately determine Lys requirements since all the other AA in formulation are calculated as a ratio to Lys [97].

Statistics/Research Methods

The most common method used to determine specific AA requirements is the dose-response study. Within this approach, the requirement is the minimal AA amount required to improve population responses for one or multiple variables during a certain period. At the same time, broiler performance response to feeding graded levels of a specific AA during certain ages/pre-determined feeding period is also evaluated [98].

To obtain the graded levels for this method, synthetic AA can be supplemented in gradual levels or the dilution technique can be used [99, 100]. Although the graded supplementation technique was reported to be the most applied in poultry studies [101], previous literature has criticized this method due to the change in the AA balance caused by the addition of graded levels of the tested AA in the diets, which may affect broiler responses it [102-104]. The dilution technique consists of the dilution and blending of two diets, a summit and a deficient in the tested AA, to create the intermediate levels of tested AA. This technique was previously reported to be more reliable than the supplementation technique, as it allows for less variation in the AA ratios among the tested levels [103].

In addition, various methods for predicting AA requirements have been evaluated. The most studied methods are the ideal protein concept, the partitioning of the requirement into maintenance and performance, and mathematical modeling. The ideal protein concept is an easy way to formulate diets for different ingredients, sexes, strains, and environmental conditions, allowing the inclusion of an alternative ingredient in the diet without having to determine the total AA requirements of this diet and, providing a rapid response in determining of AA requirements of a new strain [105]. The second approach is based on determining the amount of AA needed to meet requirements for maintenance and production, by measuring performance, nitrogen balance, and protein deposition in the muscles and feathers [106-107].

The third approach, mathematical modeling (linear and non-linear models) has been reported to be a useful method to estimate the most profitable AA level and the most efficient feeding strategy for broilers under a wide range of conditions, which is important due to the constant genetic improvement in the poultry industry [100]. Although, identifying the best statistical model to interpreting nutrient requirement studies is critical.

Linear functions in a linear model cannot be used to estimate AA requirements, only quadratic functions can be applied to estimate some requirements. Non-linear models, such as asymptotic, linear- and curvilinear-plateau, are often used [95]. In the asymptotic model, a response curve increases at a decreasing rate until reaching the maximum point, and then decreases as the nutrient level increases [95]. The maximum point represents the requirement or the predicted nutrient level that results in the maximum response, with 95% of the asymptote being previously reported to be the most feasible percentage [108].

For both linear- and curvilinear-plateau models the requirement is the level required to reach the plateau, represented by the intersection point of the ascending line and the plateau, where the optimal performance level has been met [95, 98]. The linear broken-line model has a first order polynomial for the ascending region, and both the ascending portion and the plateau are straight lines. While, in the quadratic broken-line model, the ascending region has a polynomial function of second degree and is curved. Both broken-line models may fit data well and clearly define the requirement, however the quadratic broken-line is reported to be the most suitable for most responses [95]. It is important to note that economic implications should be taken into consideration for commercial feed formulation, regardless of the model used [109].

Conclusion

Genetic selection, along with advancements in nutrition and management in the past several decades has resulted in an efficient poultry industry that will be of utmost importance in feeding the growing world population. To maintain this trajectory, primary breeders are continuously striving to optimize performance of the existing broiler crosses. At the same time, nutritionists are always researching new feeding strategies to maximize performance and reduce production costs.

In line with improving genetics of modern broilers, Cobb-Vantress developed a new broiler breeder product, the Cobb MV male, which led to the production of a new commercial broiler cross, the Cobb MV × Cobb 500. Due to this being a new cross, there is no published data on its nutritional specifications. Since several factors (such as strain, age, and sex) can affect nutritional requirements, research is needed to determine the best feeding strategy for this new broiler cross.

To optimize performance and reduce production costs, different feeding strategies have been intensively studied. Among them, varying AA density (AAD) of diets has proven to impact broiler performance. This is due to the importance of AA, e.g. Lys, in muscle accretion and other metabolic processes. In addition, feeding different levels of AA in conjunction with AME has been reported to affect broiler performance. Therefore, the objective of this dissertation is to provide valuable information on the response of this new broiler cross to varying feeding strategies during the starter and grower phases, as well as determining the digestible Lys (dLys) requirements of Cobb MV × Cobb 500 males during the first fourteen days of age. Data produced from this research can significantly impact the commercial industry by providing nutritional recommendations of this new broiler cross to the growers in effort to optimize its performance.

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CHAPTER II

EVALUATING THE RESPONSE OF COBB MV × COBB 500 BROILERS TO VARYING AMINO ACID DENSITY REGIMENS FOR A SMALL BIRD PROGRAM

Summary

Primary breeder companies are continuously striving to improve existing commercial broiler crosses to increase performance and reduce cost. The objective of this study was to evaluate the response of a new commercial broiler cross (Cobb MV × Cobb 500) under four different AA density (AAD) regimens on live performance and carcass yield during a 36 d grow-out period with two processings to collect data at d 32 and 35. Two basal diets were formulated to Low AAD (LAAD, digestible lysine, dLys 1.08, 0.95 and 0.87% for starter, grower and finisher) and Very High AAD (VHAAD, dLys 1.39, 1.26 and 1.12%). Medium and High AAD (MAAD and HAAD) diets were created by mixing the LAAD and VHAAD diets at ratios of 66.6:33.3 and 33.3:66.6, respectively. This was a randomized complete block design (RCBD) with 12 replications/treatment (16 birds/pen, 0.07 m^2/bird). Feed intake/bird (FI) was reduced when birds were fed the VHAAD diet at d 0-32 and 0-35. As AAD increased, feed conversion ratio (FCR) decreased significantly in a stepwise manner by approximately 4 points at each AAD level. Feeding higher levels of AAD improved broiler live performance and carcass yields. At d 33, birds fed the HAAD diet had the highest potential gross profit/bird, and at d 36, birds fed the VHAAD diet had

the highest potential gross profit/bird. Further research should evaluate the effects of feeding increased AAD diets to male and female Cobb MV × Cobb 500 separately, as well as in different feeding phases and longer grow-out periods.

Description of the Problem

The majority of broiler production costs are due to feed and feed manufacture. To reduce these production costs and optimize performance, primary breeder companies are continuously striving to improve nutrient utilization of new commercial broiler crosses. Selection for growth performance characteristics for breeder offspring is counterproductive to reproduction efficiency [1]. The Cobb 500 female line is reported to efficiently grow on least cost diets, while also having a low feed conversion ratio (FCR) and good hatchability (85.6%) [2]. The Cobb MX male is reported to have improved fertility from the previous male line, as well as increased yield and average daily gain at the broiler level [3]. In effort to further improve the male line performance, a new broiler breeder product was developed, the Cobb MV male; this line has been reported to demonstrate improvements in FCR at the broiler level, while maintaining fertility and hatchability from the previous Cobb MX line [4]. This has led to the production of a new commercial broiler cross, the Cobb MV × Cobb 500; and therefore, research is needed to evaluate the response of this new commercial broiler cross to different nutritional specifications in order to maximize performance.

There are many feeding strategies that have been studied to optimize broiler performance; one strategy represents feeding increased amino acid (AA) density (AAD) diets [5-7]. Previous research has demonstrated positive broiler performance responses to increased dietary AAD regimens, depending upon strain [5, 6, 8, 9]. However, in general, feeding high AAD diets to broilers improves FCR and meat yield, which could potentially increase the economic return [5, 7].

Currently, there is no published literature regarding the effects of AAD regimens on the growth performance and carcass yield of this new commercial broiler cross (Cobb MV × Cobb 500). Additionally, the target weight of broilers can vary from 1.5 to 3 kg or more depending on the market demand across the U.S. and world [10]. Therefore, the objective of this study was to evaluate the response of Cobb MV × Cobb 500 broilers to four AAD regimes to maximize d 32 and 35 performance of this new broiler cross, ultimately improving potential profit for poultry producers.

Materials and Methods

Egg Management

A total of 1,431 fertilized eggs (Cobb MV × Cobb 500) from a 37-week-old breeder flock were obtained from a commercial hatchery [11]. All eggs were stored at 18ºC for 3 d prior to incubation. On d 0, all eggs were individually weighed and labeled; they were then put into labeled flats (30 eggs/flat) and equally distributed in 3 Natureform single-stage setters [12].

On d 11, all eggs were candled and candle-residue was performed to remove infertile and contaminated eggs, as well as early dead embryos. On d 18, all eggs were in-ovo [13] vaccinated for Marek's disease (Hvt/Sb1 full dose) [14]. Immediately following vaccination, eggs were transferred to labeled hatching baskets and set into the hatchers. Then, on day of hatch, chicks were wing banded and individually weighed prior to placement in the grow-out facility.

Candle and Hatch residue analysis

Candle-residue was performed on d 11 of incubation, whereas all infertile egg, early, and mid-dead were removed from the incubator [12]. On d 21 of incubation, hatch-residue was performed in which all contaminated, cracked or pipped egg, abnormal embryo, and late-dead were counted. Hatchability was calculated taking into consideration the total number of incubated fertilized eggs on d 0 of incubation and total number of eggs and embryos removed after candle and hatch-residue analyses. Descriptive data demonstrated a high hatchability (89.8%) due to the low % infertile eggs (1.96%).

Broiler Management

A total of 16 chicks (straight-run) were assigned to each of 48 floor pens (0.07 m^2/bird). To avoid incubation effects (different hatcher and basket/position in the hatcher), all hatched chicks from a common basket (top or bottom) and hatcher (1, 2 or 3) were placed in a common block. There were 2 replications (2 blocks) per hatcher.

Water and feed were offered *ad libitum* throughout the study, and all pens contained used litter (top-dressed with fresh shavings), a hanging feeder, and 3 nipple drinkers. Birds were placed in a solid-walled facility with forced-air heating and evaporative cooling cells. To obtain cross-ventilation, negative air pressure was used.

On d 0 (day of chick placement), the house temperature was 32.2°C and it was gradually decreased until reaching 18.3°C at the end of the study on d 36 [15]. Birds received light for 24 h from d 0 to 7, and 4 h of dark from d 7 to the end of this study (d 36). The light intensity was 26.9 lux during the first 10 d. The lighting intensity was decreased on d 10 until reaching 2.7 lux on d 21 and remained so until d 35 [15].

Treatment Outline

The AAD regimes used in this study were: Low AAD (LAAD = Starter dLys 1.08%, Grower dLys 0.95%, and Finisher dLys 0.87%); Medium AAD (MAAD = Starter dLys 1.18%, Grower dLys 1.05%, and Finisher dLys 0.95%); High AAD (HAAD = Starter dLys 1.28%, Grower dLys 1.15%, and Finisher dLys 1.03%); and Very High AAD (VHAAD = Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%). The starter phase was considered to be from d 0-11, the grower phase from d 11-21 and the finisher phase from d 21-35.

Experimental Diet Preparations

Diet Formulation

Two basal diets were formulated to LAAD (Starter dLys 1.08%, Grower dLys 0.95%, and Finisher dLys 0.87%) and VHAAD (Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%; Tables 2.1 and 2.2). Prior to batching, corn, soybean meal, distillers dried grains and solubles, as well as meat and bone meal were scanned into the Near Infrared (NIR) Spectroscopy [16] at Mississippi State University. This was done to obtain available nutrient values in order to formulate diets to make them as close as possible to target nutrients, including AAD.

Batching

All basal diets were batched at the Poultry Research Unit, Mississippi State University; any ingredient with the inclusion under 0.5% of diet was included in a premix (e.g. synthetic amino acids, minerals and vitamins; Table 2.1). Premixes were made by mixing the designated ingredients in a small mixer (capacity of ~11 kg) for 5 min. All macro ingredients (e.g. corn, soybean meal, distiller's dried grains with solubles), as well as the appropriate premixes were mixed in a vertical screw mixer (with capacity of 0.907-tonne) [17] for 5 min dry. Next, diets were mixed for 10 min post fat addition and then equally/randomly allocated to a treatment, prior to pelleting. MAAD and HAAD diets were created by mixing the LAAD and VHAAD diets at ratios of 66.5:33.5 and 33.5:66.5, respectively. It is important to note that the goal AAD for MAAD blended diets was to be based on broiler recommendations for the Cobb 500 [18].

Feed Manufacture

All diets were pelleted at the Poultry Research Unit, U.S. Department of Agriculture (Starkville, MS) in order of increasing AAD. Diets were steam conditioned at 81°C (10 s) with a 262 kPa incoming steam pressure. For diet analysis, feed samples of LAAD and VHAAD from all feeding phases (Starter, Grower, and Finisher) were collected before and after pelleting and sent to commercial laboratory [19] for AA analysis [20] (Table 2.2). The starter diet was fed from d 0 to 11 as crumbles and the grower diet was presented as crumble from d 11 to 15 and as pellets during d 15 to 21; the finisher was fed from d 21 to 35 as pellets.

Measured Variables

Live Performance

On d 7, 11, 21, 32, and 35, all broiler tag numbers and corresponding individual weights were obtained. Feed intake (FI), FCR (corrected for mortality), average body weight (BW), BW gain (BWG), coefficient of variation (CV) of BW were calculated from d 0 to 7; 0 to 11; 0 to 21; 0 to 32; and 0 to 35. Total lysine intake (g/bird) was calculated utilizing the analyzed total lysine of the diet (Table 2.2) fed during the feeding period and multiplying it by the intake during each respective feeding period. For all mortality throughout the experiment, sex and cause of death was observed via necropsy. Additionally, sex was determined based on phenotypic characteristics at d 32 and 35 to analyze the sex effect and uniformity of this new commercial broiler cross. Mississippi State University Institutional Animal Care and Use Committee guidelines in agreement with the Guide for the Care and Use of Agricultural Animals Research and Teaching [21] were followed for this experiment. All live performance variables are displayed in Tables 2.3-2.11.

Processing Measurements

Processing was conducted at the Mississippi State University Poultry Processing Plant on d 33 (target weight was 1.8 kg) and d 35 (target weight was 2.3 kg), as they are common target weights for a small bird program in the US and different parts of the world. Both processings followed the same procedure in which two males and two females were selected per pen (± 100 g avg. BW of each sex/pen; total of 192 birds/processing), weighed, and tagged. Selected broilers were hung by their feet in shackles (on automated processing line) and were stunned by electrical stunning (an electric current running through a water bath). After stunning, broilers were exsanguinated using a knife to cut their necks. Next, broilers were submerged in hot water (52-66°C) to facilitate the feather removal by an automated plucking machine equipped with rubber fingers. Following, feet were manually removed at the hock joint, and carcasses were hung on a second automated line, where heads and necks were mechanically removed, and evisceration occurred. Abdominal fat pads of each carcass were removed and kept for weight recording. Then, hot carcasses were removed from the automated line and weighed. After recording the weights of hot carcasses and abdominal fat pad, all carcasses were cooled for 3 h in an ice bath. Next, all carcasses were deboned and the following weights were obtained: boneless skinless breast (pectoralis major), tender (pectoralis minor), total breast (pectoralis major and minor), thigh, drumstick, and wing. Processing yield data was calculated relative to live BW (Tables 2.7-2.12).

Economic Analysis

To evaluate the profitability of each AAD diet, the diet cost, the production costs per bird (in cents and dollar; from d 0 to 32 and from d 0 to 35), the potential gross chicken part value, and the potential cost savings/potential profit for each AAD (in cents and dollars) were calculated based on ingredient prices from Feedstuffs and USDA [22, 23] and chicken part values in the market [24]; see equations below. These data are shown in Tables 2.16 and 2.17.

Potential gross chicken part values = Processing data (chicken parts wt in kg) * Chicken part value in the market (cents) (2.1)

Total potential gross chicken part value/bird (cents) = sum of all potential gross chicken part values/bird (2.2)

Total feed cost/bird (cents) = Average feed intake (kg) * Feed cost (cents/kg) (2.3)

Total feed cost/bird (dollars) = Total feed cost/bird (cents) / 100 (2.4)

Gross bird profit (cents) = Total potential gross profit/bird (cents) – Total feed cost/bird (cents) (2.5)

Gross bird profit (dollars; in kg) = Gross bird profit (cents) / 100 (2.6)

Statistical Analysis

This study utilized a randomized complete block design (RCBD) with 4 AAD diets and 12 replicated floor pens per each treatment (12 blocks; designated by location) for FI, FCR, and BWG. One floor pen with 16 birds (0.07 sq m/bird) was considered as the experimental unit; the experimental period was from d 0-35. For BW, CV of BW, and processing, a RCBD with split plot was utilized, in which whole plots were AAD diets, and sex served as the split plot.

All measured variables were analyzed by the GLM procedure in SAS [25]. In addition, PROC CORR was used for correlation analysis between total lysine intake (g/bird) and BWG, as well as FCR. Also, PROC REG was utilized for regression analyses between dlys and FCR, as well as average FI/bird. A P-value of ≤ 0.05 was considered significant, and significant differences were further explored by Fisher's least significant difference.

Results and Discussion

Feed Analysis

Formulated diets were analyzed for total analyzed AA composition and are displayed in Table 2.2. The analyzed and calculated values were similar across diets tested.

Broiler Performance

Feed Intake

Results for d 0-7, 0-11, and 0-21 demonstrated that the birds fed the VHAAD diet had the lowest FI/bird, while birds fed the LAAD diet had the highest FI ($P<0.05$; Tables 2.3-2.5). These results are in agreement with a previous study with Cobb × Cobb 500 straight-run birds in which a decreased FI was observed when fed diets formulated to increased AA density at d 0-28 [10]. In addition, d 0-32 data showed that birds fed LAAD, MAAD, and HAAD diets had similar and higher FI when compared with birds fed VHAAD diets ($P<0.05$; Table 2.6). Additionally, d 0-35 data showed that birds fed LAAD had higher FI when compared with birds fed HAAD and VHAAD, with MAAD performing similar. While, birds fed MAAD and HAAD had similar FI; and feeding VHAAD resulted in birds with lower FI than those fed LAAD and MAAD ($P<0.05$; Table 2.7). Similarly, a previous study evaluating Ross × Ross 508 (male and female) found that feeding high AAD diet decreased feed consumption from 18 to 35 d of age [9].

Lysine Intake

Birds fed HAAD and VHAAD diets had higher d 0-7 lysine intake as compared to birds fed LAAD and MAAD, in which birds fed LAAD and MAAD demonstrated similar lysine intake ($P<0.05$; Table 2.3). However, no significant difference was observed for d 0-11 lysine intake ($P>0.05$; Table 2.4). Furthermore, it was observed for d 0-21, 0-32, and 0-35 that birds fed HAAD and VHAAD diets had higher lysine intake when compared with those fed LAAD and MAAD diets, with those fed LAAD having the lowest lysine intake ($P<0.05$; Tables 2.5-2.7).

Mortality

Though mortality in the current study was high, mortality was not affected by the dietary treatment during the rearing period ($P>0.05$; Tables 2.3-2.7). Previously, mortality was unaffected by different AAD diets throughout all phases [26]. All mortality in the current study were necropsied and the main reason was due to *E. coli* infection. Research has suggested that the amino acid requirement for birds that are immunosuppressed may be reduced [27, 28]; therefore, the performance of birds in the current study may be understated. Though, once again, it is important to note that there was no significance difference in mortality (P>0.05; Table 2.3-2.7).

Feed Conversion Ratio

Birds fed the VHAAD diet had the lowest d 0-7 mortality corrected FCR compared to birds fed the other treatments (P<0.05; Table 2.3). Similar to this study, previous research has found a benefit in corrected FCR at d 14, 28, 42, and 56, when feeding increased AAD diets to broilers from 3 different strains; however, this study [6] was published in 2005 and the highest AAD fed was comparable to the MAAD in the current study.

Additionally, results demonstrated that mortality corrected FCR (d 0-11, d 0-21, d 0-32, and d 0-35) incrementally decreased in a stepwise manner (the differences ranged from 4 to 9 points, i.e. 1.277 vs. 1.237) when birds were fed diets increasing in AAD (P<0.05; Tables 2.4-2.7). In agreement, Taschetto, et al. [10] reported a decrease in FCR (corrected for mortality) when Cobb × Cobb 500 straight-run birds were fed higher AAD diets, which were similar to higher AAD diets in the current study, as compared to those fed the low AAD diet at d 0-28 and d 0-40. Also, based on this current study, this new broiler cross had a better mortality corrected FCR (when feeding HAAD and VHAAD diets at d 32, and all AAD diets at d 35) than the reported FCR in the broiler performance manual (1.48 at d 32, and 1.53 at d 35) [18].

Body Weight Gain

Previous research reported that BWG was not affected by varying AAD during d 1-19 [29]. Similar to this study, BWG was not affected by the dietary treatments during d 0-7, 0-11, 0-32, and 0-35 ($P>0.05$; Tables 3, 4, 6, 7). However, d 0-21 data demonstrated that birds fed HAAD and VHAAD diets had higher BWG than those fed the LAAD diet, and birds receiving MAAD diets had intermediate BWG ($P<0.05$; Table 2.5).

Body Weight

A significant interaction of AAD × sex was observed for d 32 BW, in which females had the lowest BW regardless of AAD. For males, an improvement in BW was observed as AAD level increased, with males fed VHAAD diet having the highest BW, which was similar to those fed HAAD diet. Among AAD, male broilers fed LAAD diet had the lowest BW, followed by those that were provided MAAD diets, which performed similar to those fed HAAD diet.

For the main effect of AAD, BW was lower in birds fed the LAAD diet from d 21 when compared to those fed MAAD, HAAD, and VHAAD diets ($P<0.05$; Table 2.8). However, no significant difference was observed for BW at d 7, 11 and 35; as well as CV of BW ($P>0.05$; Table 2.8). These results are inconsistent with a previous study in which Ross × Ross 508 males and females were fed increased AAD diets, resulting in improved BW at d 14, 28, 35, and 49 [5]. However, it should be noted that their highest AAD diet was similar to the MAAD in the current study; a longer grow-out, as well as a different strain were utilized [5].

For the main effect of sex, significant differences were found for BW at d 11, 21, and 35; as well as CV of BW at d 7 ($P<0.05$; Table 2.8), in which male broilers had higher

BW than females in all cases; these differences were in agreement with those previously reported [30, 31]. On the other hand, no significant differences were observed for BW d 7, and CV of BW at d 11, 21, 32, and 35 ($P>0.05$; Table 2.8); and this was partially similar to a study conducted by Lopez, et al. [32], in which no significant difference was found for CV of BW due to sex or strain. Additionally, the current study's broiler cross demonstrated a higher BW when compared to current broiler performance standards (regardless of AAD or sex at d 32 and for male broilers at d 35) [18].

Processing (d 33 and 36)

No significant AAD × sex interaction was observed for any measured variable at d 33 and d 35 ($P>0.05$; Tables 2.12-2.15). For the main of AAD, results of d 33 processing demonstrated no significant difference for carcass, tender, drumstick, wing, and thigh yields (relative to live weight at d 32); as well as thigh and wing weights ($P>0.05$; Tables 2.12 and 2.13). Processing data (d 36) demonstrated no significant difference for carcass, drumstick, thigh, and wing (relative to d 35 live weight); as well as drumstick, thigh, and wing weights ($P>0.05$; Tables 2.14 and 2.15).

An improvement in breast and tender weight at d 33 was observed when birds were fed MAAD, HAAD, and VHAAD diets, when compared to those fed the LAAD diet ($P<0.05$, Table 2.13). Similarly, Taschetto and cohorts [10] concluded that feeding increased AAD diets maximized breast meat yields. In contrast, previous research feeding similar AAD regimes demonstrated no AAD effect on carcass yield and breast weight [8, 26].

Based on this study, birds fed HAAD and VHAAD diets had greater tender yield (relative to d 35 live weight) when compared to birds fed the LAAD diet ($P<0.05$). Tender weight increased when birds were fed the VHAAD diet as compared to those fed the LAAD diet, with birds receiving MAAD and HAAD diets performing similar (P<0.05; Tables 2.14 and 2.15). In agreement, Corzo, et al. [6] reported higher tender yields (relative to live weight) at d 42 and 56 (which were longer than the processing periods for the current study), when birds were fed the high AAD diet as compared to those fed the low AAD diet; however, their high AAD diet was equivalent to the MAAD diet in the current study.

Breast yield relative to d 32 live weight resulted in an improvement when birds were fed diets formulated to either MAAD, HAAD, or VHAAD as compared to those fed the LAAD diet (P<0.05; Table 2.12). This result is in agreement with previous findings [5, 7, 8, 26], in which breast meat yield was shown to be affected by dietary AAD; feeding higher AAD diets exhibited an increase in breast meat yield on broilers when compared to feeding the LAAD diet. In addition, d 36 processing demonstrated that birds fed MAAD and VHAAD had greater breast yield (relative to d 35 live weight) and weight when compared to birds fed the LAAD diet (P<0.05; Tables 2.14 and 2.15). Additionally, d 33 processing resulted in birds fed HAAD and VHAAD diets having greater d 32 live weight and drumstick weight when compared to birds fed the LAAD diet (P<0.05; Tables 2.12 and 2.13).

Lastly, it was observed that on d 33 and d 36 processing that feeding the VHAAD diet decreased fat pad yield (relative to d 32 and d 35 live weight) and weight of broilers, with birds receiving the HAAD diet performing similar (P<0.05; Tables 2.12-2.15). Unlike the present study, it was previously found that abdominal fat weight was not affected when feeding different AAD diets [7]. However, the current study is in agreement with previous studies, in which abdominal fat pad yield and weight were reported to be affected by different AAD diets [5, 6, 8, 9]. Providing higher AAD diets to broilers has been shown to decrease abdominal pad fat yield and weight in comparison to feeding the LAAD diet [7, 26].

For the main of sex, as expected, some benefits in processing characteristics were found when comparing male to female broilers, such as a greater average live weight at d 32 and 35, drumstick yield (relative to d 32 and d 35 live weight), drumstick and wing weights at d 33 and 36, as well as breast and thigh weights at d 36 (P<0.05; Tables 2.12-2.15). This was somewhat in agreement with previous work that observed that males had higher carcass and breast weight compared with females [32, 33].

Additionally, the current study found that females had greater tender and fat pad yield (relative to d 32 and d 35 live weight), as well as fat pad weight at d 33 when compared to males (P<0.05; Tables 2.9-2.11). These results are in partial agreement with a study conducted by Kidd, et al. [31], in which females were reported to have a lower tender yield when compared with males. It was previously reported that females had a higher abdominal fat pad than males, which might be due to differences between sex and their body metabolism, fat accumulation, and nutritional requirement [6, 34].

Correlation Analysis

Significant correlations were observed for total lysine intake and BWG at d 0-7 (P= 0.0011*;* R= 0.4645); d 0-11 (P<0.0001; R= 0.7137); d 0-21 (P<0.0001; R= 0.7488); d 0-32 (P<0.0001; R= 0.7595); and d 0-35 (P<0.0001; R= 0.7081; Table 2.9). No correlations (P>0.05) were observed for total lysine intake and FCR at d 0-7 or d 0-11. Though, strong correlations were observed for total lysine intake and FCR at d 0-21 (P<0.0001; R= -0.6829); d 0-32 (P<0.0001; R= -0.6674); and d 0-35 (P<0.0001; R= -0.6414; Table 2.9).

Regression Analysis

Based on this study, d 0-7 and 0-11 data demonstrated that FCR decreased linearly with increasing dLys levels ($P<0.05$; Table 2.10). In addition, significant quadratic relationships between FCR and dLys were observed at d 0-21, 0-32, and 0-35 ($P<0.0001$; Table 2.10). Lastly, based on d 0-7, 0-32, and 0-35 data, FI decreased linearly with increasing dLys levels; while d 0-11 data showed a significant quadratic relationship between FI and dLys ($P<0.05$; Table 2.11).

Economic Analysis (d 33 and 35)

At 33 d of age, the potential cost saving/potential gross profit per bird was greater on birds fed the HAAD diet (Table 2.16). While at 36 d of age, the highest potential cost saving/potential gross profit per bird was observed on birds fed the VHAAD diet (Table 2.17). Based on economic return, the higher breast weight at d 32 for birds fed the HAAD diet provided an increase of $0.16 in potential gross chicken part value when compared to birds fed the LAAD diet. An increase of $0.18 in potential gross chicken part value for birds fed VHAAD diet vs. LAAD diet at d 36 was also observed.

In addition, birds fed the LAAD diet demonstrated the lowest potential saving/potential gross profit per bird in both periods. However, it is important to point out that these potential gross savings or profits were calculated only during a specific period of time (a 32 and 35 d grow-out period in July of 2017) [22, 23]. Therefore, it is essential to constantly reconsider the relationship between feed costs and processing yield, since feed ingredients and chicken part values have been instable and change periodically [26].

Summary and Future Direction

This study emphasizes the importance of considering several factors (such as age and market) when evaluating the response of a new commercial broiler cross (Cobb MV × Cobb 500) to different AAD diets. Feeding increased AAD decreased FCR and FI, as well as improved BWG (d 21), BW (d 21 and 32) and some processing characteristics. Based on this, performance data demonstrated a better mortality corrected FCR (HAAD and VHAAD diets at d 32; and all AAD diets at d 35) in comparison to what was previously found by Zhai, et al. [26] (FCR = 1.58 when feeding MAAD diets at d 35). In addition, a greater BW was observed when feeding all diets at d 35 in comparison to the BW reported by Zhai, et al. (1.95 kg when feeding MAAD at d 35) [26]. Because it is also known that sex and age can affect nutrition requirements, further research is needed to evaluate the effects of feeding different AAD diets in male and female Cobb MV × Cobb 500 separately, as well as longer grow-out periods. Additionally, future small bird research should compare the economics on different commercial broiler crosses.

Conclusion and Applications

1. Feeding diets with higher levels of AAD improved live performance of the Cobb MV × Cobb 500 broiler cross. These data were supported by correlation and regression analyses. Perhaps most notable, these improvements were found with FCR (mortality corrected) at d 32 and 35 by approximately 4 and 6 points, respectively.
2. Interestingly, for d 32 BW, males were more sensitive to AAD of diets than females, whereas feeding VHAAD diets maximized BW for males. Females responded similarly at d 32 for BW, regardless of AAD.

3. Diet AAD elicited varied responses from Cobb MV × Cobb 500 broilers, depending upon age of processing:

a. At d 33, feeding broilers MAAD or higher resulted in improved (but similar) breast yield (relative to live weight), as well as breast and tender weights, as compared to birds fed LAAD diets.

b. At d 36, feeding broilers VHAAD diets consistently resulted in the highest numerical breast and tender yields (relative to live weight) and weights, respectively. While these birds at times performed similar to broilers fed MAAD and/or HAAD diets, birds fed MAAD and/or HAAD diets also on occasion performed similar to birds fed LAAD diets.

4. Based on our economic model, feeding broilers the HAAD diet (Starter dLys 1.28%, Grower dLys 1.15%, and Finisher dLys 1.03%) was the most profitable at d 33, while feeding broilers the VHAAD (Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%) diet was the most profitable at d 36.

Table 2.1. Diet formulations for starter, grower and finisher phases[1]

Ingredient Name	Starter (d 0-11)		Grower (d 11-21)		Finisher (d 21-35)	
	Low AAD	Very High AAD	Low AAD	Very High AAD	Low AAD	Very High AAD
	Inclusion %	Inclusion %	Inclusion %	Inclusion %	Inclusion %	Inclusion %
Corn	66.88	51.75	71.30	55.49	65.81	61.73
Soybean meal (48% CP)	21.46	35.45	17.45	31.82	17.81	25.36
DDGS[2]	3.00	3.00	4.00	4.00	5.00	5.00
Defluorinated phosphate	0.976	0.964	0.865	0.854	0.904	0.884
Calcium carbonate	0.514	0.447	0.510	0.441	0.537	0.511
Salt, NaCl	0.102	0.120	0.111	0.132	0.175	0.155
Meat and bone meal (57% CP)	4.00	4.00	3.00	3.00	2.58	2.58
Poultry fat	0.500	2.69	0.500	2.88	3.14	2.53
DL-Methionine	0.290	0.394	0.242	0.343	0.206	0.312
Sand	1.12	-	0.969	-	3.00	-
Sodium S-Carb	0.314	0.295	0.248	0.223	0.157	0.184
Vitamin-trace mineral	0.250	0.250	0.250	0.250	0.250	0.250
L-Lysine HCl	0.375	0.336	0.350	0.300	0.253	0.327
L-Threonine	0.079	0.180	0.081	0.147	0.079	0.091
L-Valine	0.014	0.012	0.011	0.003	-	-
Selenium premix 0.06%	0.024	0.024	0.024	0.024	-	-
Phytase[3]	0.011	0.011	0.011	0.011	0.011	0.011
Antibiotic[4]	0.050	0.050	0.050	0.050	0.050	0.050
Coccidiostat[5]	0.040	0.040	0.030	0.030	0.030	0.030
Nutrient Name	**Calculated Nutrients (%)[6]**					
Crude protein (%)	19.55	25.40	17.53	23.48	17.20	20.77
AME (kcal/kg)	3024.17	3024.17	3074.16	3074.16	3124.15	3124.15
Digestible lysine (%)	1.08	1.39	0.950	1.26	0.870	1.12
Digestible threonine (%)	0.680	0.960	0.610	0.860	0.610	0.730
Digestible methionine (%)	0.553	0.717	0.487	0.650	0.448	0.592
Digestible cysteine (%)	0.257	0.313	0.243	0.299	0.232	0.268
Digestible methionine + Digestible cysteine (%)	0.810	1.03	0.730	0.950	0.680	0.860
Digestible arginine (%)	1.11	1.51	0.970	1.38	0.960	1.19
Digestible isoleucine (%)	0.726	0.966	0.637	0.883	0.639	0.780
Digestible leucine (%)	1.56	1.89	1.44	1.77	1.43	1.64
Digestible valine (%)	0.820	1.04	0.730	0.950	0.717	0.851
Digestible tryptophan (%)	0.194	0.271	0.168	0.247	0.170	0.214
Digestible phenylalanine (%)	0.838	1.09	0.750	1.01	0.747	0.898
Calcium (%)	0.940	0.940	0.870	0.870	0.820	0.820
Available phosphorus (%)	0.470	0.470	0.435	0.435	0.410	0.410
Sodium (%)	0.230	0.230	0.200	0.200	0.200	0.200
Chloride (%)	0.200	0.200	0.200	0.200	0.215	0.215

[1]Low amino acid (AA) density (AAD); Very High AAD; Medium AAD diet was composed of 66.5% Low AAD and 33.5% Very High AAD; and High AAD diet was composed of 33.5% Low AAD and 66.5% Very High AAD
[2]Corn distillers dried grains with solubles
[3]Quantum Blue (E.Coli phytase). AB Vista, Plantation, FL.
[4]BMD-50 (bacitracin methylene disalicylate). Zoetis, Parsippany, NJ.
[5]Nicarb 25% (Nicarbazin). Phibro, Teaneck, NJ.
[6]Values are calculated based on the analyzed AA composition of corn, soybean meal, corn DDGs, and animal by-product blend

Table 2.2. Analyzed and Total AA profile for starter, grower and finisher feed samples

Amino acid (AA)	Starter (d 0-11)				Grower (crumble; d 11-12)				Grower (pellet; d 15-21)				Finisher (d 21-35)			
	Low AAD		Very High AAD		Low AAD		Very High AAD		Low AAD		Very High AAD		Low AAD		Very High AAD	
	Analyzed[1]	Total[2]	Analyzed	Total	Analyzed	Total	Analyzed	Total	Analyzed	Total	Analyzed	Total	Analyzed	Total	Analyzed	Total
Lysine	1.27	1.22	1.48	1.57	1.20	1.08	1.31	1.43	1.13	1.08	1.47	1.43	0.98	1.00	1.15	1.27
Methionine	0.68	0.58	0.79	0.75	0.51	0.51	0.59	0.68	0.50	0.51	0.73	0.68	0.52	0.45	0.60	0.62
Cysteine	0.37	0.33	0.44	0.40	0.35	0.19	0.41	0.28	0.34	0.19	0.41	0.28	0.32	0.30	0.45	0.34
Tryptophan	0.22	0.22	0.29	0.31	0.18	0.19	0.24	0.28	0.19	0.19	0.25	0.28	0.18	0.20	0.20	0.24
Threonine	0.80	0.81	1.02	1.12	0.70	0.72	0.97	1.00	0.74	0.72	1.08	1.00	0.70	0.72	0.80	0.86
Isoleucine	0.79	0.82	0.99	1.09	0.67	0.72	0.86	1.00	0.69	0.72	0.98	1.00	0.70	0.72	0.79	0.88
Valine	0.89	0.97	1.05	1.23	0.79	0.86	0.92	1.12	0.80	0.86	1.06	1.12	0.80	0.84	0.86	1.00
Arginine	1.26	1.22	1.52	1.65	1.10	1.06	1.34	1.50	1.14	1.06	1.56	1.50	1.13	1.05	1.22	1.30
Leucine	1.58	1.72	1.88	2.09	1.44	1.58	1.74	1.96	1.45	1.58	1.84	1.96	1.51	1.57	1.64	1.81
Phenylalanine	0.92	-	1.10	-	0.79	-	0.99	-	0.82	-	1.11	-	0.84	-	0.91	-

[1]Feed samples were analyzed in duplicate at ATC Scientific. North Little Rock, AR. Official Methods of Analysis of AOAC International: Amino acid (AA) by Performic acid (Cysteine and Methionine); AA by Sodium hydroxide (Tryptophan); AA by Hydrochloric acid (all other AA)

[2]Total value was obtained from formulation; macro ingredients, i.e. corn, soybean meal, corn DDGS, and meat and bone meal were analyzed at ATC labs prior to diet formulation in attempt to more accurately formulate diets to digestible AA goals at each dietary phase

Table 2.3. The effect of varying Amino Acid Density (Low, Medium, High or Very High) on d 0 to 7 Cobb broiler performance[1]

Amino Acid Density (AAD)[2]	d 0-7 Avg[3] FI/bird[4] (kg)	d 0-7 Total Lysine intake (g)/bird[5]	d 0-7 Percent Mortality[6]	d 0-7 Mortality Corrected FCR[7]	d 0-7 BWG[8] (kg)
Low	0.159[a]	2.003[b]	3.646	1.124[a]	0.139
Medium	0.153[b]	2.046[b]	4.688	1.102[ab]	0.135
High	0.152[b]	2.147[a]	3.125	1.094[b]	0.141
Very High	0.147[c]	2.164[a]	3.125	1.048[c]	0.140
Fisher's LSD[9]	0.0082	0.0520	-	0.0294	-
P-value[10]	<0.0001	<0.0001	0.7859	<0.0001	0.2337
SEM[11]	0.0013	0.0180	1.2365	0.0102	0.0019

[1]For FI, FCR, and BWG, a RCBD with 4 AAD diets and 12 replicated floor pens per each treatment utilized
[2]Low AAD (Amino Acid Density) = Starter dLys (digestible lysine) 1.08%, Grower dLys 0.95%, and Finisher dLys 0.87%; Medium AAD = Starter dLys 1.18%, Grower dLys 1.05%, and Finisher dLys 0.95%; High AAD = Starter dLys 1.28%, Grower dLys 1.15%, and Finisher dLys 1.03%; and Very High AAD = Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%. It is important to note that MAAD was formulated based on breeder recommendation for Cobb 500.
[3]Average
[4]Feed Intake/bird (kg)
[5]Total Lysine intake (g)/bird was calculated utilizing the analyzed total lysine of the diet (Table 2) fed during the feeding period and multiplying it by the intake during the feeding period on a per bird basis
[6]Percent Mortality is based on a beginning pen number of 16 birds
[7]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[8]Body Weight Gain (kg)
[9]Fisher's Least Significant Difference
[10]Alpha set at $P \leq 0.05$
[11]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[a-c]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 2.4. The effect of varying Amino Acid Density (Low, Medium, High or Very High) on d 0 to 11 Cobb broiler performance[1]

Amino Acid Density (AAD)[2]	d 0-11 Avg[3] FI/bird[4] (kg)	d 0-11 Total Lysine intake (g) /bird[5]	d 0-11 Percent Mortality[6]	d 0-11 Mortality Corrected FCR[7]	d 0-11 BWG[8] (kg)
Low	0.370[a]	3.195	5.208	1.282[a]	0.284
Medium	0.359[ab]	3.197	5.729	1.237[b]	0.289
High	0.352[b]	3.290	3.125	1.193[c]	0.292
Very High	0.340[c]	3.246	4.688	1.155[d]	0.291
Fisher's LSD[9]	0.0231	-	-	0.0242	-
P-value[10]	<0.0001	0.3090	0.6273	<0.0001	0.3650
SEM[11]	0.0036	0.0385	1.4675	0.0084	0.0030

[1]For FI, FCR, and BWG, a RCBD with 4 AAD diets and 12 replicated floor pens per each treatment utilized
[2]Low AAD (Amino Acid Density) = Starter dLys (digestible lysine) 1.08%, Grower dLys 0.95%, and Finisher dLys 0.87%; Medium AAD = Starter dLys 1.18%, Grower dLys 1.05%, and Finisher dLys 0.95%; High AAD = Starter dLys 1.28%, Grower dLys 1.15%, and Finisher dLys 1.03%; and Very High AAD = Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%. It is important to note that MAAD was formulated based on breeder recommendation for Cobb 500.
[3]Average
[4]Feed Intake/bird (kg)
[5]Total Lysine intake (g)/bird was calculated utilizing the analyzed total lysine of the diet (Table 2) fed during the feeding period and multiplying it by the intake during the feeding period on a per bird basis
[6]Percent Mortality is based on a beginning pen number of 16 birds
[7]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[8]Body Weight Gain (kg)
[9]Fisher's Least Significant Difference
[10]Alpha set at $P \leq 0.05$
[11]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[a-d]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 2.5. The effect of varying Amino Acid Density (Low, Medium, High or Very High) on d 0 to 21 Cobb broiler performance[1]

Amino Acid Density (AAD)[2]	**d 0-21 Avg[3] FI/bird[4] (kg)**	**d 0-21 Total Lysine intake (g) /bird[5]**	**d 0-21 Percent Mortality[6]**	**d 0-21 Mortality Corrected FCR[7]**	**d 0-21 BWG[8] (kg)**
Low	1.260[a]	13.337[c]	8.333	1.438[a]	0.876[b]
Medium	1.224[b]	13.935[b]	5.729	1.363[b]	0.896[ab]
High	1.214[b]	14.628[a]	5.208	1.314[c]	0.915[a]
Very High	1.141[c]	14.676[a]	5.208	1.269[d]	0.909[a]
Fisher's LSD[9]	0.0672	0.3868	-	0.0202	0.0496
P-value[10]	<0.0001	<0.0001	0.6330	<0.0001	0.0179
SEM[11]	0.0106	0.1339	1.9661	0.0070	0.0078

[1]For FI, FCR, and BWG, a RCBD with 4 AAD diets and 12 replicated floor pens per each treatment utilized
[2]Low AAD (Amino Acid Density) = Starter dLys (digestible lysine) 1.08%, Grower dLys 0.95%, and Finisher dLys 0.87%; Medium AAD = Starter dLys 1.18%, Grower dLys 1.05%, and Finisher dLys 0.95%; High AAD = Starter dLys 1.28%, Grower dLys 1.15%, and Finisher dLys 1.03%; and Very High AAD = Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%. It is important to note that MAAD was formulated based on breeder recommendation for Cobb 500.
[3]Average
[4]Feed Intake/bird (kg)
[5]Total Lysine intake (g)/bird was calculated utilizing the analyzed total lysine of the diet (Table 2) fed during the feeding period and multiplying it by the intake during the feeding period on a per bird basis
[6]Percent Mortality is based on a beginning pen number of 16 birds
[7]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[8]Body Weight Gain (kg)
[9]Fisher's Least Significant Difference
[10]Alpha set at $P \leq 0.05$
[11]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[a-d]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 2.6. The effect of varying Amino Acid Density (Low, Medium, High or Very High) on d 0 to 32 Cobb broiler performance[1]

Amino Acid Density (AAD)[2]	d 0-32 Avg[3] FI/bird[4] (kg)	d 0-32 Total Lysine intake (g) /bird[5]	d 0-32 Percent Mortality[6]	d 0-32 Mortality Corrected FCR[7]	d 0-32 BWG[8] (kg)
Low	2.923[a]	29.402[c]	9.375	1.554[a]	1.870
Medium	2.877[a]	31.073[b]	5.729	1.498[b]	1.919
High	2.847[a]	32.404[a]	5.729	1.469[c]	1.928
Very High	2.756[b]	33.011[a]	6.250	1.425[d]	1.928
Fisher's LSD[9]	0.1792	0.8367	-	0.0196	-
P-value[10]	0.0041	<0.0001	0.5158	<0.0001	0.1081
SEM[11]	0.0282	0.2893	1.9905	0.0068	0.0169

[1]For FI, FCR, and BWG, a RCBD with 4 AAD diets and 12 replicated floor pens per each treatment utilized
[2]Low AAD (Amino Acid Density) = Starter dLys (digestible lysine) 1.08%, Grower dLys 0.95%, and Finisher dLys 0.87%; Medium AAD = Starter dLys 1.18%, Grower dLys 1.05%, and Finisher dLys 0.95%; High AAD = Starter dLys 1.28%, Grower dLys 1.15%, and Finisher dLys 1.03%; and Very High AAD = Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%. It is important to note that MAAD was formulated based on breeder recommendation for Cobb 500.
[3]Average
[4]Feed Intake/bird (kg)
[5]Total Lysine intake (g)/bird was calculated utilizing the analyzed total lysine of the diet (Table 2) fed during the feeding period and multiplying it by the intake during the feeding period on a per bird basis
[6]Percent Mortality is based on a beginning pen number of 16 birds
[7]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[8]Body Weight Gain (kg)
[9]Fisher's Least Significant Difference
[10]Alpha set at $P \leq 0.05$
[11]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[a-d]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 2.7. The effect of varying Amino Acid Density (Low, Medium, High or Very High) on d 0 to 35 Cobb broiler performance[1]

Amino Acid Density (AAD)[2]	d 0-35 Avg[3] FI/bird[4] (kg)	d 0-35 Total Lysine intake (g)/bird[5]	d 0-35 Percent Mortality[6]	d 0-35 Mortality Corrected FCR[7]	d 0-35 BWG[8] (kg)
Low	3.183[a]	31.951[c]	9.375	1.519[a]	2.104
Medium	3.157[ab]	33.981[b]	5.729	1.465[b]	2.172
High	3.082[bc]	35.283[a]	5.729	1.430[c]	2.166
Very High	3.037[c]	36.231[a]	6.250	1.394[d]	2.175
Fisher's LSD[9]	0.0855	1.0144	-	0.0156	-
P-value[10]	0.0048	<0.0001	0.5158	<0.0001	0.0837
SEM[11]	0.0329	0.3512	1.9905	0.0054	0.0220

[1]For FI, FCR, and BWG, a RCBD with 4 AAD diets and 12 replicated floor pens per each treatment utilized
[2]Low AAD (Amino Acid Density) = Starter dLys (digestible lysine) 1.08%, Grower dLys 0.95%, and Finisher dLys 0.87%; Medium AAD = Starter dLys 1.18%, Grower dLys 1.05%, and Finisher dLys 0.95%; High AAD = Starter dLys 1.28%, Grower dLys 1.15%, and Finisher dLys 1.03%; and Very High AAD = Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%. It is important to note that MAAD was formulated based on breeder recommendation for Cobb 500.
[3]Average
[4]Feed Intake/bird (kg)
[5]Total Lysine intake (g)/bird was calculated utilizing the analyzed total lysine of the diet (Table 2) fed during the feeding period and multiplying it by the intake during the feeding period on a per bird basis
[6]Percent Mortality is based on a beginning pen number of 16 birds
[7]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[8]Body Weight Gain (kg)
[9]Fisher's Least Significant Difference
[10]Alpha set at $P \leq 0.05$
[11]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[a-d]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 2.8. The effect of varying Amino Acid Density (Low, Medium, High or Very High) on d 0, 7, 11, 21, 32 and 35 body weight, and coefficient of variation of body weight[1]

Amino Acid Density (AAD)[2]	Sex	d 0 BW[3] (kg)	CV[4] d 0 BW (%)	d 7 BW[3] (kg)	CV[4] d 7 BW (%)	d 11 BW[3] (kg)	CV[4] d 11 BW (%)	d 21 BW[3] (kg)	CV[4] d 21 BW (%)	d 32 BW[3] (kg)	CV[4] d 32 BW (%)	d 35 BW[3] (kg)	CV[4] d 35 BW (%)
Low	**Female**	0.044	5.933	0.184	7.794	0.328	7.833	0.885	8.993	1.828[d]	9.675	2.021	11.221
Medium		0.043	7.817	0.181	6.920	0.332	5.735	0.906	7.083	1.850[d]	8.551	2.038	1.627
High		0.043	7.924	0.182	6.496	0.332	5.992	0.913	6.735	1.858[d]	7.381	2.037	7.007
Very High		0.043	7.350	0.182	7.396	0.330	7.418	0.897	10.475	1.866[d]	8.189	2.053	9.087
Low	**Male**	0.044	6.634	0.184	7.681	0.333	6.731	0.932	7.473	1.982[c]	8.487	2.284	9.287
Medium		0.044	8.652	0.177	11.045	0.342	7.709	0.970	8.564	2.062[b]	8.374	2.397	7.235
High		0.043	7.101	0.185	8.281	0.331	7.851	1.004	8.480	2.091[ab]	8.707	2.400	9.258
Very High		0.044	8.099	0.183	8.537	0.338	9.108	0.992	9.040	2.132[a]	8.407	2.440	9.245
Fisher's LSD[5]		-	-	-	-	-	-	-	-	0.0051	-	-	-
SEM[6]		0.0005	0.6168	0.0021	1.1039	0.0033	0.9287	0.0112	1.3153	0.0190	1.1099	0.0265	1.6639
Main effect of AAD													
Low		0.044	6.283	0.184	7.737	0.331	7.282	0.909[b]	8.233	1.906	9.081	2.153	10.254
Medium		0.043	8.235	0.179	8.982	0.332	6.722	0.938[a]	7.824	1.957	8.462	2.218	8.589
High		0.043	7.512	0.183	7.389	0.337	6.921	0.959[a]	7.608	1.975	8.044	2.218	8.133
Very High		0.043	7.724	0.182	7.966	0.334	8.263	0.945[a]	9.757	1.999	8.298	2.240	9.166
SEM[6]		0.0003	0.5199	0.0021	1.0409	0.0029	0.6768	0.0098	1.0498	0.0199	0.6322	0.0266	0.9001
Main effect of Sex													
Female		0.043	7.256	0.182	7.151[b]	0.330[b]	6.745	0.900[b]	8.322	1.850	8.449	2.037[b]	9.315
Male		0.044	7.621	0.182	8.886[a]	0.336[a]	7.850	0.974[a]	8.389	2.067	8.494	2.380[a]	8.715
SEM[6]		0.0002	0.3084	0.0011	0.5519	0.0016	0.4643	0.0056	0.6577	0.0095	0.5549	0.0187	0.8332
P-values													
AAD[7]		0.5052	0.0737	0.2629	0.7308	0.4513	0.3949	0.0089	0.4747	0.0151	0.6932	0.1030	0.3694
Sex[8]		0.1200	0.4066	0.8550	0.0315	0.0193	0.0995	<0.0001	0.9424	<0.0001	0.9549	<0.0001	0.6381
AAD × Sex[9]		0.6609	0.4854	0.4349	0.2875	0.3419	0.2987	0.1166	0.4372	0.0391	0.7267	0.1091	0.4327

[1]For BW and coefficient of variation of BW, a RCBD with split plot was utilized, in which whole plots were AAD diets, and sex served as the split plot
[2]Low AAD (Amino Acid Density) = Starter dLys (digestible lysine) 1.08%, Grower dLys 0.95%, and Finisher dLys 0.87%; Medium AAD = Starter dLys 1.18%, Grower dLys 1.05%, and Finisher dLys 0.95%; High AAD = Starter dLys 1.28%, Grower dLys 1.15%, and Finisher dLys 1.03%; and Very High AAD = Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%. It is important to note that MAAD was formulated based on breeder recommendation for Cobb 500.
[3]Body Weight (kg)
[4]Coefficient of variation of BW
[5]Fisher's Least Significant Difference
[6]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[7]P-values for AAD main effect; alpha set at P≤0.05
[8]P-values for Sex main effect; alpha set at P≤0.05
[9]P-values for AAD x Sex interaction; alpha set at P≤0.05
[a-b]Values within columns with different superscripts differ significantly (P<0.05)

Table 2.9. Correlations between Total Lysine Intake and Body Weight Gain, as well as Total Lysine Intake and Feed Conversion Ratio (d 0-7; 0-11; 0-21; 0-32; and 0-35)

Total Lys intake[1] and BWG[2]	**d 0-7 Lys intake/bird[3] and BWG**	**d 0-11 Lys intake/bird[4] and BWG**	**d 0-21 Lys intake/bird[5] and BWG**	**d 0-32 Lys intake/bird[6] and BWG**	**d 0-35 Lys intake/bird[7] and BWG**
R	0.4645	0.7137	0.7488	0.7595	0.7081
P-values	0.0011	<0.0001	<0.0001	<0.0001	<0.0001

Total Lys intake[1] and FCR[8]	**d 0-7 Lys intake/bird[3] and FCR**	**d 0-11 Lys intake/bird[4] and FCR**	**d 0-21 Lys intake/bird[5] and FCR**	**d 0-32 Lys intake/bird[6] and FCR**	**d 0-35 Lys intake/bird[7] and FCR**
R	-0.0251	0.0719	-0.6829	-0.6674	-0.6414
P-values	0.8669	0.6309	<0.0001	<0.0001	<0.0001

[1]Total Lys intake (g)/bird was calculated utilizing the analyzed total Lys of the diet (Table 2) fed during the feeding period and multiplying it by the intake during the feeding period on a per bird basis
[2]Body weight gain (kg)
[3]Lys intake/bird on d 0-7 (g), which was calculated using d 0-7 feed intake/bird and analyzed Lys/diet
[4]Lys intake/bird on d 0-11 (g), which was calculated using d 0-11 feed intake/bird and analyzed Lys/diet
[5]Lys intake/bird on d 0-21 (g), which was calculated using d 0-21 feed intake/bird and analyzed Lys/diet
[6]Lys intake/bird on d 0-32 (g), which was calculated using d 0-32 feed intake/bird and analyzed Lys/diet
[7]Lys intake/bird on d 0-35 (g), which was calculated using d 0-35 feed intake/bird and analyzed Lys/diet
[8]Feed Conversion Ratio (corrected for mortality)

Table 2.10. Regression analysis for Feed Conversion Ratio and digestible lysine (through treatment means)

Days of grow-out	Relationship between FCR[1] and dLys[2]	Linear model			Quadratic model			
		Model P-Value	Linear slope P-Value	R^2 Value	Model P-Value	Linear slope P-Value	Quadratic slope P-Value	R^2 Value
d 0-7	Linear[3]	0.0474	0.0474	0.9075	0.2098	0.5411	0.4846	-
d 0-11	Linear[4]	0.0030	0.0030	0.9941	0.0545	0.8097	0.5017	-
d 0-21	Quadratic[5]	<0.0001	<0.0001	-	<0.0001	0.0296	0.1115	0.8652
d 0-32	Quadratic[6]	<0.0001	<0.0001	-	<0.0001	0.0933	0.2297	0.8010
d 0-35	Quadratic[7]	<0.0001	<0.0001	-	<0.0001	0.0604	0.1605	0.8018

[1]Feed Conversion Ratio (corrected for mortality)
[2]Digestible lysine (%)
[3]Calculated values were derived using the regression equation: $y = -0.2303x + 1.37636$; where y = FCR and x = dLys
[4]Calculated values were derived using the regression equation: $y = -0.38571x + 1.69463$; where y = FCR and x = dLys
[5]Calculated values were derived using the regression equation: $y = 0.54948x^2 - 1.88405x + 2.82574$; where y = FCR and x = dLys
[6]Calculated values were derived using the regression equation: $y = 0.40038x^2 - 1.39726x + 2.59440$; where y = FCR and x = dLys
[7]Calculated values were derived using the regression equation: $y = 0.46467x^2 - 1.55290x + 2.65590$; where y = FCR and x = dLys

Table 2.11. Regression analysis for average feed intake and digestible lysine (through treatment means)

Days of grow-out	Relationship between FI[1] and dLys[2]	Linear model			Quadratic model			
		Model P-Value	Linear slope P-Value	R^2 Value	Model P-Value	Linear slope P-Value	Quadratic slope P-Value	R^2 Value
d 0-7	Linear[3]	0.0434	0.0434	0.9151	0.2869	0.9671	0.8885	-
d 0-11	Quadratic[4]	0.0270	0.0270	-	0.0412	0.1142	0.1356	0.9983
d 0-21	-	0.0523	0.0523	-	0.2166	0.5273	0.4747	-
d 0-32	Linear[5]	0.0215	0.0215	0.9574	0.1321	0.5262	0.4424	-
d 0-35	Linear[6]	0.0258	0.0258	0.9491	0.0850	0.2918	0.2460	-

[1]Feed Intake (g)
[2]Digestible lysine (%)
[3]Calculated values were derived using the regression equation: $y = -33.53789x + 193.79047$; where y = FI and x = dLys
[4]Calculated values were derived using the regression equation: $y = -215.59794x^2 + 446.82935x + 133.34985$; where y = FI and x = dLys
[5]Calculated values were derived using the regression equation: $y = -491.88979x + 3463.37089$; where y = FI and x = dLys
[6]Calculated values were derived using the regression equation: $y = -665.57029x + 4986.99938$; where y = FI and x = dLys

Table 2.12. The effect of varying Amino Acid Density (Low, Medium, High or Very High) on processing characteristics (d 33) reported as average yield relative to d 32 live weight[1]

Amino Acid Density (AAD)[2]	Sex	Avg[3] d 32 BW (kg)	Yield relative to d 32 live weight[4] (%)						
			Carcass	Breast[5]	Tender[6]	Drumstick	Thigh	Wing	Fat Pad
Low	**Female**	1.894	65.863	15.525	3.657	8.704	11.736	7.996	1.588
Medium		1.937	66.652	16.566	3.803	8.736	12.085	7.828	1.282
High		1.961	66.736	16.857	3.922	8.729	11.791	7.765	1.287
Very High		1.942	67.011	17.205	3.889	8.622	11.863	7.835	1.079
Low	**Male**	1.928	65.924	15.835	3.611	8.824	11.817	7.905	1.175
Medium		1.966	66.898	16.635	3.708	8.971	11.779	8.072	1.099
High		2.015	66.723	16.954	3.609	9.048	11.622	7.929	0.909
Very High		2.025	66.428	16.528	3.659	9.071	12.045	7.869	0.834
Fisher's LSD[7]		-	-	-	-	-	-	-	-
SEM[8]		0.0185	0.3364	0.2655	0.0750	0.1472	0.1430	0.0861	0.0804
Main effect of AAD									
Low		1.911[b]	65.894	15.680[b]	3.634	8.764	11.776	7.951	1.381[a]
Medium		1.952[ab]	66.775	16.600[a]	3.756	8.854	11.932	7.950	1.190[b]
High		1.988[a]	66.730	16.905[a]	3.765	8.889	11.707	7.847	1.098[bc]
Very High		1.984[a]	66.719	16.866[a]	3.774	8.847	11.954	7.852	0.966[c]
SEM[8]		0.0192	0.3272	0.1928	0.0512	0.0911	0.1298	0.0609	0.0586
Main effect of Sex									
Female		1.934[b]	66.565	16.538	3.818[a]	8.698[b]	11.869	7.856	1.309[a]
Male		1.984[a]	66.493	16.488	3.647[b]	8.978[a]	11.815	7.944	1.010[b]
SEM[8]		0.0092	0.3364	0.2655	0.0750	0.1472	0.1430	0.0861	0.0414
P-values									
AAD[9]		0.0271	0.1894	0.0002	0.1968	0.7995	0.4738	0.4444	0.0002
Sex[10]		0.0004	0.7638	0.7904	0.0024	0.0100	0.6000	0.1574	<0.0001
AAD × Sex[11]		0.4557	0.6416	0.2790	0.2768	0.7225	0.3113	0.2367	0.4449

[1]For BW and coefficient of variation of BW, a RCBD with split plot was utilized, in which whole plots were AAD diets, and sex served as the split plot
[2]Low AAD (Amino Acid Density) = Starter dLys (digestible lysine) 1.08%, Grower dLys 0.95%, and Finisher dLys 0.87%; Medium AAD = Starter dLys 1.18%, Grower dLys 1.05%, and Finisher dLys 0.95%; High AAD = Starter dLys 1.28%, Grower dLys 1.15%, and Finisher dLys 1.03%; and Very High AAD = Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%. It is important to note that MAAD was formulated based on breeder recommendation for Cobb 500.
[3]Average
[4]Yield Relative to Live Body Weight (%)
[5]Breast refers to the pectoralis major
[6]Tender refers to the pectoralis minor
[7]Fisher's Least Significant Difference
[8]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[9]P-values for AAD main effect; alpha set at $P \leq 0.05$
[10]P-values for Sex main effect; alpha set at $P \leq 0.05$
[11]P-values for AAD × Sex interaction; alpha set at $P \leq 0.05$
[a-c]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 2.13. The effect of varying Amino Acid Density (Low, Medium, High or Very High) on processing characteristics (d 33) reported as average weight[1]

Amino Acid Density (AAD)[2]	**Sex**	**Avg weight[3] (kg)**					
		Breast[4]	**Tender[5]**	**Drumstick**	**Thigh**	**Wing**	**Fat Pad**
Low	**Female**	0.294	0.069	0.165	0.222	0.151	0.030
Medium		0.321	0.074	0.169	0.235	0.152	0.025
High		0.331	0.077	0.171	0.231	0.152	0.025
Very High		0.334	0.076	0.168	0.231	0.152	0.021
Low	**Male**	0.305	0.070	0.170	0.228	0.152	0.023
Medium		0.328	0.073	0.176	0.232	0.159	0.022
High		0.342	0.073	0.182	0.234	0.160	0.018
Very High		0.335	0.074	0.184	0.244	0.159	0.017
Fisher's LSD[6]		-	-	-	-	-	-
SEM[7]		0.0057	0.0014	0.0032	0.0035	0.0019	0.0016
Main effect of AAD							
Low		0.299[b]	0.069[b]	0.167[b]	0.225	0.151	0.026[a]
Medium		0.324[a]	0.073[a]	0.173[ab]	0.233	0.155	0.023[ab]
High		0.336[a]	0.075[a]	0.177[a]	0.233	0.156	0.022[bc]
Very High		0.335[a]	0.075[a]	0.176[a]	0.237	0.156	0.019[c]
SEM[7]		0.0051	0.0013	0.0022	0.0037	0.0017	0.0012
Main effect of Sex							
Female		0.320	0.074	1.168[b]	0.230	0.152[b]	0.025[a]
Male		0.327	0.072	0.178[a]	0.234	0.157[a]	0.020[b]
SEM[7]		0.0027	0.0007	0.0016	0.0018	0.0010	0.0009
P-values							
AAD[8]		<0.0001	0.0224	0.0193	0.1472	0.2220	0.0017
Sex[9]		0.0683	0.1628	<0.0001	0.0576	0.0002	<0.0001
AAD × Sex[10]		0.7759	0.4322	0.3791	0.1330	0.2644	0.4628

[1]For BW and coefficient of variation of BW, a RCBD with split plot was utilized, in which whole plots were AAD diets, and sex served as the split plot
[2]Low AAD (Amino Acid Density) = Starter dLys (digestible lysine) 1.08%, Grower dLys 0.95%, and Finisher dLys 0.87%; Medium AAD = Starter dLys 1.18%, Grower dLys 1.05%, and Finisher dLys 0.95%; High AAD = Starter dLys 1.28%, Grower dLys 1.15%, and Finisher dLys 1.03%; and Very High AAD = Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%. It is important to note that MAAD was formulated based on breeder recommendation for Cobb 500.
[3]Average weight (kg)
[4]Breast refers to the pectoralis major
[5]Tender refers to the pectoralis minor
[6]Fisher's Least Significant Difference
[7]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[8]P-values for AAD main effect; alpha set at P≤0.05
[9]P-values for Sex main effect; alpha set at P≤0.05
[10]P-values for AAD × Sex interaction; alpha set at P≤0.05
[a-c]Values within columns with different superscripts differ significantly (P<0.05)

Table 2.14. The effect of varying Amino Acid Density (Low, Medium, High or Very High) on processing characteristics (d 36) reported as average yield relative to d 35 live weight[1]

Amino Acid Density (AAD)[2]	Sex	Avg[3] d 35 BW (kg)	Yield Relative to d 35 Live Weight[4] (%)						
			Carcass	Breast[5]	Tender[6]	Drumstick	Thigh	Wing	Fat Pad
Low	**Female**	2.118	68.202	16.538	3.961	9.098	12.208	7.824	1.509
Medium		2.132	66.372	17.493	4.057	9.039	12.343	7.813	1.492
High		2.137	68.938	17.637	4.093	9.170	12.273	7.806	1.325
Very High		2.127	68.783	18.072	4.082	9.039	12.366	7.622	1.115
Low	**Male**	2.231	67.511	16.750	3.620	9.489	11.969	7.891	1.216
Medium		2.333	67.849	17.663	3.734	9.371	12.231	7.537	1.282
High		2.312	67.899	17.203	3.784	9.226	12.075	7.619	1.076
Very High		2.364	68.241	17.759	3.956	9.235	12.395	7.885	1.028
Fisher's LSD[7]		-	-	-	-	-	-	-	-
SEM[8]		0.0245	0.8033	0.3095	0.0755	0.0930	0.1688	0.154	0.0884
Main effect of AAD									
Low		2.175	67.856	16.644[b]	3.791[b]	9.293	12.089	7.858	1.363[ab]
Medium		2.233	67.110	17.578[a]	3.900[ab]	9.205	12.287	7.675	1.387[a]
High		2.224	68.419	17.420[ab]	3.939[a]	9.198	12.174	7.713	1.201[bc]
Very High		2.247	68.572	17.977[a]	4.026[a]	9.116	12.399	7.733	1.059[c]
SEM[8]		0.0304	0.6080	0.2785	0.0478	0.0926	0.1332	0.0990	0.0628
Main effect of Sex									
Female		2.128[b]	68.074	17.435	4.051[a]	9.086[b]	12.298	7.766	1.360[a]
Male		2.312[a]	67.891	17.362	3.772[b]	9.324[a]	12.172	7.722	1.146[b]
SEM[8]		0.0215	0.4298	0.1969	0.0338	0.0655	0.0942	0.0700	0.0444

Table 2.14 (continud)

P-values								
AAD[9]	0.3945	0.3574	0.0218	0.0185	0.7047	0.4539	0.5937	0.0041
Sex[10]	<0.0001	0.7282	0.6793	<0.0001	0.0006	0.2818	0.7639	0.0017
AAD × Sex[11]	0.0963	0.3935	0.6353	0.4648	0.2801	0.8688	0.3084	0.6959

[1]For BW and coefficient of variation of BW, a RCBD with split plot was utilized, in which whole plots were AAD diets, and sex served as the split plot

[2]Low AAD (Amino Acid Density) = Starter dLys (digestible lysine) 1.08%, Grower dLys 0.95%, and Finisher dLys 0.87%; Medium AAD = Starter dLys 1.18%, Grower dLys 1.05%, and Finisher dLys 0.95%; High AAD = Starter dLys 1.28%, Grower dLys 1.15%, and Finisher dLys 1.03%; and Very High AAD = Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%. It is important to note that MAAD was formulated based on breeder recommendation for Cobb 500.

[3]Average

[4]Yield Relative to [1]Live Body Weight (%)

[5]Breast refers to the pectoralis major

[6]Tender refers to the pectoralis minor

[7]Fisher's Least Significant Difference

[8]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean

[9]P-values for AAD main effect; alpha set at P≤0.05

[10]P-values for Sex main effect; alpha set at P≤0.05

[11]P-values for AAD × Sex interaction; alpha set at P≤0.05

[a-c]Values within columns with different superscripts differ significantly (P<0.05)

Table 2.15. The effect of varying Amino Acid Density (Low, Medium, High or Very High) on processing characteristics (d 36) reported as average weight[1]

Amino Acid Density (AAD)[2]	Sex	Avg Weight[3] (kg)					
		Breast[4]	Tender[5]	Drumstick	Thigh	Wing	Fat Pad
Low	**Female**	0.350	0.084	0.193	0.259	0.166	0.032
Medium		0.374	0.087	0.193	0.263	0.166	0.032
High		0.377	0.087	0.196	0.262	0.167	0.029
Very High		0.386	0.087	0.192	0.263	0.162	0.024
Low	**Male**	0.375	0.081	0.212	0.267	0.176	0.028
Medium		0.413	0.087	0.219	0.285	0.176	0.030
High		0.398	0.088	0.213	0.279	0.176	0.025
Very High		0.420	0.094	0.218	0.293	0.186	0.024
Fisher's LSD[6]		-	-	-	-	-	-
SEM[7]		0.0084	0.0019	0.0032	0.0050	0.0034	0.0021
Main effect of AAD							
Low		0.363[b]	0.082[b]	0.202	0.263	0.171	0.030[a]
Medium		0.393[a]	0.087[ab]	0.206	0.274	0.171	0.031[a]
High		0.387[ab]	0.088[ab]	0.205	0.271	0.171	0.027[ab]
Very High		0.405[a]	0.091[a]	0.205	0.279	0.174	0.024[b]
SEM[7]		0.0100	0.019	0.0036	0.0048	0.0030	0.0015
Main effect of Sex							
Female		0.372[b]	0.0863	0.194[b]	0.262[b]	0.165[b]	0.029
Male		0.402[a]	0.0873	0.215[a]	0.282[a]	0.178[a]	0.027
SEM[7]		0.0071	0.0013	0.0026	0.0034	0.0021	0.0010

Table 2.15 (continued)

P-values						
AAD[8]	0.0463	0.0504	0.9189	0.1612	0.8704	0.0118
Sex[9]	<0.0001	0.4408	<0.0001	<0.0001	<0.0001	0.1089
AAD × Sex[10]	0.6858	0.1142	0.3702	0.2184	0.0953	0.6320

[1]For BW and coefficient of variation of BW, a RCBD with split plot was utilized, in which whole plots were AAD diets, and sex served as the split plot

[2]Low AAD (Amino Acid Density) = Starter dLys (digestible lysine) 1.08%, Grower dLys 0.95%, and Finisher dLys 0.87%; Medium AAD = Starter dLys 1.18%, Grower dLys 1.05%, and Finisher dLys 0.95%; High AAD = Starter dLys 1.28%, Grower dLys 1.15%, and Finisher dLys 1.03%; and Very High AAD = Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%. It is important to note that MAAD was formulated based on breeder recommendation for Cobb 500.

[3]Average weight (kg)

[4]Breast refers to the pectoralis major

[5]Tender refers to the pectoralis minor

[6]Fisher's Least Significant Difference

[7]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean

[8]P-values for AAD main effect; alpha set at $P \leq 0.05$

[9]P-values for Sex main effect; alpha set at $P \leq 0.05$

[10]P-values for AAD × Sex interaction; alpha set at $P \leq 0.05$

[a-c]Values within columns with different superscripts differ significantly ($P < 0.05$)

Table 2.16. Potential gross bird profit or potential saving for each Amino Acid Density diet (d 33)

Potential gross chicken part values[1] using processing data (chicken parts weight in kg) and chicken part values in the market (cents)[2]	Amino Acid Density (AAD)			
	Low[3]	Medium[4]	High[5]	Very High[6]
Breast	100.22	108.66	112.69	112.15
Wings	65.808	67.384	67.778	67.680
Tenders	30.621	32.323	32.923	32.923
Thighs	29.854	30.908	30.908	31.479
Drumsticks	19.313	19.942	20.386	20.256
Total potential gross chicken part values/bird (cents)[7]	245.82	259.22	264.68	264.49
Total feed costs/bird (cents)[8]	63.954	65.351	67.158	67.446
Total feed costs/bird (dollars)[9]	0.6395	0.6535	0.6716	0.6745
Gross bird profit (profit processing-feed costs/bird; cents)[10]	181.87	193.86	197.52	197.05
Gross bird profit (profit processing-feed costs/bird; dollars; kg)[11]	1.819	1.939	1.975	1.971

[1]Potential gross chicken part values = Processing data (chicken parts wt in kg) * Chicken part value in the market (cents)
[2]Express Markets Incorporated (weekly report for July 7, 2017; 5-day average, Fort Wayne, IN. Chicken part prices (cents/kg): Breast = 335.09; Wings = 434.45; Tenderloins = 441.31; Thighs = 132.72; Drumsticks = 115.41)
[3]Low AAD = Starter dLys (digestible lysine) 1.08%, Grower dLys 0.95%, and Finisher dLys 0.87%
[4]Medium AAD (MAAD) = Starter dLys 1.18%, Grower dLys 1.05%, and Finisher dLys 0.95%. It is important to note that MAAD was formulated based on breeder recommendation for Cobb 500.
[5]High AAD = Starter dLys 1.28%, Grower dLys 1.15%, and Finisher dLys 1.03%
[6]Very High AAD = Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%
[7]Total potential gross chicken part value/bird (cents) = sum of the potential gross chicken part values (breast, wings, tenders, thighs, and drumsticks) per bird
[8]Total feed cost/bird (cents) = Average feed intake (kg) * Feed cost (cents/kg; ingredient prices were based from Feedstuffs - Ingredient Market Prices and USDA - Feedstuffs Reports. Ingredient prices ($/ton): Corn = $124.57; soybean meal = $328.28; distiller's dried grains with solubles = $104.45; meat and bone meal = $272.4; deflourinated phosphate = $1,520; calcium carbonate = $212; salt = $54; poultry fat = $23.63; sand = $150; sodium S-carb = $488; vitamin-trace mineral = $1,556; selenium premix = $386; DL-methionine = $2,880; L-lysine = $1,660; L-threonine = $1,940; L-valine = $9,900; phytase = $8,300; bacitracin = $7,500; nicarbazin = $898)
[9]Total feed cost/bird (dollars) = Total feed cost/bird (cents) / 100
[10]Gross bird profit (cents) = Total potential gross profit/bird (cents) – Total feed cost/bird (cents)
[11]Gross bird profit (dollars; in kg) = Gross bird profit (cents) / 100

Table 2.17. Potential gross bird profit/potential saving for each Amino Acid Density diet (d 36)

Potential gross chicken part values[1] using processing data (chicken part weight in kg) and chicken part values in the market (cents)[2]	Amino Acid Density (AAD)			
	Low[3]	Medium[4]	High[5]	Very High[6]
Breast	121.50	131.83	129.78	135.56
Wings	74.083	73.591	74.379	75.660
Tenders	36.426	38.327	38.627	39.928
Thighs	34.880	36.385	35.903	37.077
Drumsticks	23.344	23.736	23.605	23.684
Total potential gross chicken part values/bird (cents)[7]	290.23	303.87	302.30	311.91
Total feed costs/bird (cents)[8]	69.135	71.596	73.024	73.193
Total feed costs/bird (dollars)[9]	0.6913	0.7160	0.7302	0.7319
Gross bird profit (profit processing-feed costs/bird; cents)[10]	221.1	232.3	229.3	238.7
Gross bird profit (profit processing-feed costs/bird; dollars; kg)[11]	2.211	2.323	2.293	2.387

[1]Potential gross chicken part values = Processing data (chicken parts wt in kg) * Chicken part value in the market (cents)
[2]Express Markets Incorporated (weekly report for July 7, 2017; 5-day average, Fort Wayne, IN. Chicken part prices (cents/kg): Breast = 335.09; Wings = 434.45; Tenderloins = 441.31; Thighs = 132.72; Drumsticks = 115.41)
[3]Low AAD = Starter dLys (digestible lysine) 1.08%, Grower dLys 0.95%, and Finisher dLys 0.87%
[4]Medium AAD (MAAD) = Starter dLys 1.18%, Grower dLys 1.05%, and Finisher dLys 0.95%. It is important to note that MAAD was formulated based on breeder recommendation for Cobb 500.
[5]High AAD = Starter dLys 1.28%, Grower dLys 1.15%, and Finisher dLys 1.03%
[6]Very High AAD = Starter dLys 1.39%, Grower dLys 1.26%, and Finisher dLys 1.12%
[7]Total potential gross chicken part value/bird (cents) = sum of the potential gross chicken part values (breast, wings, tenders, thighs, and drumsticks) per bird
[8]Total feed cost/bird (cents) = Average feed intake (kg) * Feed cost (cents/kg; ingredient prices were based from Feedstuffs - Ingredient Market Prices and USDA - Feedstuffs Reports. Ingredient prices ($/ton): Corn = $124.57; soybean meal = $328.28; distiller's dried grains with solubles = $104.45; meat and bone meal = $272.4; deflourinated phosphate = $1,520; calcium carbonate = $212; salt = $54; poultry fat = $23.63; sand = $150; sodium S-carb = $488; vitamin-trace mineral = $1,556; selenium premix = $386; DL-methionine = $2,880; L-lysine = $1,660; L-threonine = $1,940; L-valine = $9,900; phytase = $8,300; bacitracin = $7,500; nicarbazin = $898)
[9]Total feed cost/bird (dollars) = Total feed cost/bird (cents) / 100
[10]Gross bird profit (cents) = Total potential gross profit/bird (cents) – Total feed cost/bird (cents)
[11]Gross bird profit (dollars; in kg) = Gross bird profit (cents) / 100

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CHAPTER III

EVALUATING THE DIGESTIBLE LYSINE REQUIREMENTS OF MALE COBB MV × COBB 500 BROILERS DURING THE FIRST FOURTEEN DAYS OF AGE AND THE DIETARY IMPACT ON GROWTH PERFORMANCE

Summary

Previous research demonstrated the digestible lysine (dLys) requirement for the Cobb MV × Cobb 500 from d 0-7 and 0-11 to be between 1.2–1.4%. However, it was likely the dLys requirement was not met for feed conversion ratio (FCR) and >1.4% dLys should be evaluated. Therefore, the objective was to determine the dLys requirement of Cobb MV × Cobb 500 males from d 0-14 and evaluate the dietary impact on growth performance. Two basal diets were formulated to 0.88% dLys (Treatment (Trt) 1) and 1.44% dLys (Trt 8) and were mixed to create Trts 2–7 (0.96–1.36% dLys, respectively). A control diet (1.28% dLys) was separately manufactured in order to confirm accurate mixing of blended diets. Nine dietary treatments were arranged in a randomized complete block design (RCBD), with each pen having 14 birds (0.08 m^2/bird). Linear broken line (LBL), quadratic broken line (QBL), and exponential asymptotic (EA) models were used to estimate dLys requirement. Results showed that dLys requirements varied among mathematical models and response variables. Using LBL, QBL, and EA models, dLys requirements were 1.17%, 1.30%, and 1.27%, respectively, for body weight gain (BWG). The dLys requirement using LBL was 1.29% for FCR; however, when using QBL and EA models, it was not met and

could only be calculated to be 1.49% and 1.46% dLys, respectively. Birds receiving ≥1.20% dLys demonstrated greater performance when compared to birds fed ≤1.12% dLys at d 14. Future research should evaluate higher dLys levels than those used in this study.

Description of the Problem

In an effort to improve the male line, Cobb-Vantress [1] developed a new broiler breeder product, the Cobb MV male, which was introduced into the market in 2017 [2]. This has led to the production of a new commercial broiler strain, the Cobb MV × Cobb 500. However, to optimize growth performance and meat yield of this new commercial broiler strain, more research is needed on its nutritional requirement, because it was previously reported that the bird's nutritional requirements can be influenced by several factors, such as sex, age, strain, and others [3].

Furthermore, amino acids (AA) are vital for muscle growth [4] and thus, to optimize growth performance and meat yield, it is necessary to define the digestible AA requirements every time new broiler genetics are introduced. Among all AA, lysine (Lys) is the 2nd limiting AA in the diet for broilers [5], and supplementation with adequate dietary Lys provides proper muscle development and growth performance [6]. In addition, the composition of Lys in the breast muscle is greater than other AA [4], as it represents ~7% of the protein content in the total breast [5]. Thus, determining the digestible Lys (dLys) requirement is needed to optimize growth performance of this new commercial strain. Therefore, the objectives of the current study were to evaluate the dLys requirement of male broilers of a new commercial strain (Cobb MV × Cobb 500) during the first 14 days of age as well as the dietary AA impact on d 0-14 growth performance.

Materials and Methods

Broiler Management

The current study was conducted at the Mississippi State University Poultry Research Unit. Day old Cobb MV × Cobb 500 male chicks were provided from a commercial hatchery [7] and equally allotted into 96 floor pens (0.91 x 1.22 m; 14 birds/pen; 0.08 m^2/bird) that had fresh shavings over used litter. The experimental house was solid-walled with evaporative cooling cells and forced-air heating. Feed and water were provided *ad libitum* using a hanging feeder (16.0 kg capacity) and 3 nipple drinkers per pen.

Birds were provided with 24 h of light from d 0 to 7 and 20 h of light from d 7 until the end of the study (d 42). The light intensity was 26.9 lux from d 0 to 10, and gradually decreased until reaching 2.7 lux on d 21, which was maintained until d 42 [8]. The house temperature was set at 32.2°C on d 0 and incrementally reduced until reaching 18.3°C on d 35 [8].

Experimental Diet Preparations

Diet Formulation

Prior to formulation, corn and soybean meal were analyzed for total AA content [9, 10], as well as scanned using Near Infrared (NIR) Spectroscopy [11] to obtain nutrient values for more accurate formulation. Two starter basal diets were formulated: one considered Low (Treatment (Trt) 1) – 0.88% dLys and the other a High (Trt 8) – 1.44% dLys. The other dietary treatments (Trts 2 to 7 – 0.96, 1.04, 1.12, 1.20, 1.28, and 1.36% dLys, respectively) were created by blending Trts 1 and 8 in different ratios prior to pelleting (See Table 3.1). To verify this blending technique, a control diet (Trt 9 – 1.28% dLys) was separately batched and was compared with the mixed diet (Trt 6 – 1.28% dLys).

Batching

Diet formulations can be found in Table 3.1. Micro ingredients or any ingredients with <0.5% of inclusion in the diet (such as synthetic amino acids, vitamins, minerals, and others; see Table 3.1) were weighed and mixed prior to being added in with the remaining basal ingredients. At Mississippi State University Poultry Research Unit, basal diets were batched and mixed 5 minutes dry and 10 minutes after fat inclusion in a 0.907-tonne vertical screw mixer [12].

Feed Manufacture

Dietary treatments were pelleted and crumbled at the USDA - Poultry Research Unit (Starkville, MS). On day of pelleting, appropriate proportions of Low (Trt 1 – 0.88% dLys) and High (Trt 8 – 1.44% dLys) were mixed for 5 min to create Trts 2 to 7 (0.96%, 1.04%, 1.12%, 1.20%, 1.28%, 1.36% dLys, respectively). A control diet (Trt 9 –1.28% dLys) was separately mixed for 5 min prior to pelleting. Diets were pelleted using a CPM pellet mill after 10 seconds of conditioning at 81°C and 262 kPa steam pressure. Feed samples were collected on day of pelleting throughout each run and sent for laboratory analysis (Table 3.2) [10]. Experimental diets were provided as crumbles from d 0 to 14. Common grower and finisher diets were provided to all birds from d 14-41 as pellets; additional information on grower and finisher phases have been described in another publication (Chapter 4).

Measured Variables

Live Performance

Each bird was weighed on d 7, 11, and 14; average body weight (BW), BW gain (BWG), average feed intake/bird (FI), and feed conversion ratio (FCR) adjusted for mortality from d 0 to 7, 0 to 11, and 0 to 14 were calculated. Birds were raised according to the Mississippi State University Institutional Animal Care and Use Committee guidelines in agreement with the Guide for the Care and Use of Agricultural Animals in Research and Teaching [13].

Statistical Analysis

The current study utilized a randomized complete block design (RCBD), in which 9 treatments were represented by 11 replicate floor pens (Trts 3-8) and 10 replicate floor pens (Trts 1, 2, and 9). The experimental period was from d 0-14; and each floor pen with 14 chicks/pen (0.08 m^2/bird) was considered as an experimental unit. Formulated dLys values were used in statistical analyses, because total analyzed Lys values were in agreement with formulated values.

Analyses of linear broken line (LBL) and quadratic broken line (QBL) models were conducted using the PROC NLIN option of SAS [14]. When a significant breakpoint was found ($P \leq 0.05$), broken line methodologies were used to estimate dLys requirements for BWG and FCR, in which the requirement breakpoints were confirmed in SAS [14] using the code from Robbins et al. [15].

In addition, to explain potential dLys effects, data was analyzed using PROC REG with a quadratic trend [14]. The dLys requirement was also estimated using an exponential asymptotic (EA) model, in which the dLys requirement was calculated at 95% of the asymptote when a quadratic trend was observed (P≤0.05). Additionally, all measured variables were analyzed using GLM procedure in SAS [14]; differences among means were explored by Fisher's least significant difference; and statistical significance was set at P-value ≤ 0.05.

Results and Discussion

Feed Analysis

The analyzed and calculated values for total AA composition of each formulated diet are displayed in Tables 3.1 and 3.2, in which values were similar across diets tested. The discrepancies observed between analyzed AA values for Trts 6 and 9 could be due to the sample volume and limitation in the analysis.

Regression Analysis

Significant quadratic and broken line responses (P<0.0001) were observed for increasing dietary dLys levels for BWG and FCR in the period from 0 to 14 days of age (Table 3.3). Based on BWG, data suggest that the dLys requirement for male Cobb MV × Cobb 500 from d 0-14 (Table 3.3) was 1.17% based on LBL (P<0.00001 and R^2=0.808; Figure 3.1); 1.30% based on QBL (P<0.00001 and R^2=0.819; Figure 3.2); and 1.29% based on EA (P<0.0001 and R^2=0.726; Figure 3.3). Using the LBL model, the dLys requirement for FCR was approximately 1.29% (P<0.00001 and R^2=0.924; Figure 3.4). However, the dLys requirement for FCR predicted using QBL and EA methodologies (Table 3.3) was estimated to be approximately 1.49% (P<0.00001 and R^2=0.935; Figure 3.5) and 1.47% (P<0.0001 and R^2=0.919; Figure 3.6), respectively, which were beyond the highest dLys level provided in this study (1.44%).

Based on the results of the current study, the dLys requirement for male Cobb MV × Cobb 500 broilers during the first 14 days of age ranged from 1.17-1.30% for BWG, and 1.29-1.49% for FCR. In agreement with the current study, a previous research reviewed the Lys requirements from 16 papers, with different broiler commercial strains and sexes varying from 0 to 21 d of age, and they concluded that the requirements for feed efficiency was higher than that for BWG [16]. When using an ascending line with plateau model, the Lys requirements were 1.04% for BWG and 1.10% for feed efficiency; while using an ascending quadratic with plateau model, the Lys requirements were 1.21% for BWG and 1.32% for feed efficiency [16].

Regression data suggested that the dLys requirements for this new commercial strain from d 0-14 were 1.17% for BWG and 1.29% for FCR (Table 3.3), when using LBL methodology. In addition, when using QBL methodology, the d 0-14 dLys requirement for this new commercial strain was 1.30% for BWG and approximately 1.49% for FCR. It must be noted that the highest dLys level tested was 1.44%, which is less than the estimated dLys requirement for FCR using QBL. However, the LBL methodology had a lower dLys requirement and R^2 value than the QBL model; this is in agreement with a previous study, in which the QBL model provided the best fit for performance variables [6].

Additionally, using an EA model and the metric BWG, the dLys requirement was estimated to be 1.29%. However, the dLys requirement for FCR was not met when using this statistical model and it was estimated to be 1.47%. Based on the EA model, regardless of response variable, the dLys requirement estimates are higher than those reported by Rostagno et al. [17] and Cobb 500 recommendations [8]. Furthermore, to obtain accurate requirement estimates, scientists should be aware of the pros and cons of each statistical model. For instance, broken-line models clearly define the requirement as the level of a nutrient that provides the optimum variable response [18]. The broken-line model with a linear ascending portion fits the data easier than one with a quadratic ascending portion. Polynomial models need less points/nutrient levels to get an estimate of the response curve and are easier to fit than broken-line models [18]. However, second order polynomials cannot identify the plateau between the level for maximum response and toxic levels, while the broken-line models can [18].

Broiler Performance

No significant difference was observed for percent mortality throughout the study ($P>0.05$; Tables 3.4-3.6). This is in agreement with previous research in which mortality was not affected by feeding different dLys concentrations from 1 to 15 d of age in two experiments using two different broiler strains (Ross × Ross 708 and Hubbard × Cobb 500) [5].

Results for d 0-7 demonstrated that birds fed diets formulated ≥1.12% dLys (Trts 4-9) had similar, but higher BW and BWG when compared to birds fed ≤1.04% dLys (Trts 1-3; $P<0.0001$; Table 3.4). In addition, birds fed diets formulated to 1.28% dLys (Trt 9 – Control) had greater BW and BWG when compared to birds fed ≤1.12% dLys (Trts 1-4) and 1.283% dLys (Trt 6) from d 0-11 ($P<0.0001$; Table 3.5); however, this difference in performance between Trts 6 and 9 was not observed at d 14. Birds receiving dLys of 1.20% or greater (Trts 5-9) demonstrated increased BW and BWG when compared to birds fed ≤1.12% dLys (Trts 1-4) on d 0-14, with birds fed Trts 5-9 having similar BW and BWG ($P<0.0001$; Table 3.6).

No significant difference was observed for d 0-7 FI (P>0.05; Table 3.4). However, birds fed diets formulated to 1.44% dLys (Trt 8 – High) demonstrated lower d 0-11 FI when compared to birds fed diets from 0.96 to 1.20% dLys (Trts 2-5) and 1.28% dLys (Trt 9), with birds fed Trts 0.88, 1.283, and 1.36% dLys (Trts 1, 6, and 7) having similar FI (P=0.0006; Table 3.5). On d 0-14, birds fed diets formulated to 0.88% dLys (Trt 1 - Low) and 1.44% dLys (Trt 8) demonstrated the lowest FI when compared to birds fed all other treatments (P<0.0001; Table 3.6). Contrasting to our results, an increase in FI was previously reported when birds were fed gradual levels of dLys from d 1 to 14 (Ross × Ross 708 and Hubbard × Cobb 500 females) [5]. Previous literature has demonstrated that broilers will try to adjust their feed consumption to meet their nutritional requirements [19, 20].

On d 0-7, birds receiving diets formulated to dLys levels of ≥1.12% (Trts 4-9) demonstrated lower mortality corrected FCR when compared to birds fed ≤1.04% dLys (Trts 1-3; P<0.0001; Table 3.4). Birds fed diets formulated to 1.44% dLys (Trt 8) and 1.28% dLys (Trt 9) demonstrated the lowest mortality corrected FCR from d 0-11, while those fed diets formulated to 0.88% dLys (Trt 1) had the highest mortality corrected FCR (P<0.0001; Table 3.5). On d 0-14, birds fed diets formulated to 1.44% dLys (Trt 8) demonstrated the lowest numerical mortality corrected FCR (P<0.0001; Table 3.6). The carryover effect of the experimental treatments on d 0-41 growth performance and d 42 processing of broilers in this study has been reported in a separate publication (Chapter 4).

Summary and Future Direction

This study shows the importance of considering several factors (such as mathematical model and response variable) when determining the dLys requirements of a new commercial broiler cross (Cobb MV × Cobb 500). Based on results, the dLys requirements for BWG varied from 1.17 to 1.30% for three different statistical methodologies (LBL, QBL, and EA). For FCR, the dLys requirement was 1.29% using LBL, but it was not met when using the other two models. Performance data showed that feeding ≥1.20% dLys during the starter phase improved BW and BWG at d 14. Further research should evaluate dLys levels higher than 1.44%, as well as the dLys requirements of female Cobb MV × Cobb 500 broilers during the first 14 days of age.

Conclusions and Applications

1. Digestible lysine requirements varied among statistical models and response variables. Using LBL, QBL, and EA methodologies, dLys requirements for Cobb MV × Cobb 500 male broilers from d 0-14 were 1.17%, 1.30%, and 1.29% for BWG. For mortality corrected FCR, the dLys requirement was 1.29% using LBL; however, it was not met when using QBL and EA models, and was estimated to be approximately 1.49% and 1.47% dLys, respectively.
2. Day 0-14 data demonstrated that birds fed diets formulated to ≥1.20% dLys had greater BW and BWG when compared to those fed diets formulated to ≤1.12% dLys. In addition, birds receiving diets formulated to be 1.44% dLys (Trt 8) demonstrated the numerical lowest FCR (mortality corrected), with birds fed diets formulated to 1.28% dLys (Trt 9) performing similar.

Table 3.1. Diet formulations for starter phase (d 0-14)

Ingredient Name	**Trt 1 (Low) – 0.88% dLys**	**Trt 8 (High) – 1.44% dLys**	**Trt 9 (Control)[1] – 1.28% dLys**
Corn	73.50	46.20	54.00
Soybean meal (48% CP)	22.30	45.20	38.60
Soybean oil	0.99	5.30	4.06
Defluorinated phosphate	1.43	1.27	1.32
Calcium carbonate	0.59	0.51	0.54
Salt	0.23	0.24	0.38
L-Lysine HCl	0.16	0.15	0.15
L-Threonine	0.08	0.16	0.14
L-Valine	-	0.05	0.03
Phytase[2]	0.01	0.01	0.01
DL-Methionine	0.19	0.45	0.24
Sodium S-Carb	0.15	0.15	0.15
Vitamin-trace mineral	0.25	0.25	0.25
Selenium premix 0.06%	0.02	0.02	0.02
Choline Cl-70%	0.10	0.01	0.04
Antibiotic[3]	0.05	0.05	0.05
Coccidiostat[4]	0.04	0.04	0.04
Nutrient Name	**Calculated Nutrients (%)[5]**		
AME (kcal/kg)	3051.72	3051.72	3051.72
Crude protein (%)	16.10	25.00	22.50
Crude fat (%)	3.30	7.10	6.10
Linoleic acid (%)	1.48	1.06	1.17
Calcium (%)	0.90	0.90	0.90
Total phosphorus (%)	0.59	0.64	0.63
Available phosphorus (%)	0.45	0.45	0.45
Sodium (%)	0.22	0.22	0.22
Potassium (%)	0.66	1.03	0.92
Chloride (%)	0.22	0.21	0.21
Na+K-Cl (mEq/kg)	201.00	301.00	272.00
Digestible lysine (%)	0.88	1.44	1.28
Digestible methionine (%)	0.44	0.79	0.69
Digestible methionine + Digestible cysteine (%)	0.68	1.11	0.99
Digestible tryptophan (%)	0.16	0.28	0.24
Digestible threonine (%)	0.59	0.96	0.86
Digestible isoleucine (%)	0.61	0.99	0.88
Digestible valine (%)	0.69	1.11	0.99
Digestible arginine (%)	0.95	1.58	1.40
Choline (mg/kg)	1543.24	1543.24	1543.24

[1]Treatment (Trt) 9 was the control diet (1.28% digestible lysine (dLys)), which was made to compare to the mixed diet Trt 6 (1.283% dLys). Low (Trt 1 – 0.88% dLys) and High (Trt 8 – 1.44% dLys) basal diets were batched and mixed in different ratios prior pelleting for creation of Trts 2-7. Listed below are each treatment and their respective ratios:

Trt 1 = 100:0 (Low:High)
Trt 2 = 85:15
Trt 3 = 70:30
Trt 4 = 57:43

Trt 5 = 42:58
Trt 6 = 28:72
Trt 7 = 15:85
Trt 8 = 0:100

[2]Quantum Blue (*E.Coli* phytase). AB Vista, Plantation, FL.
[3]BMD-50 (bacitracin methylene disalicylate). Zoetis, Parsippany, NJ.
[5]Nicarb 25% (Nicarbazin). Phibro, Teaneck, NJ.
[5]Values are calculated based on the analyzed nutrient composition of corn and soybean meal

Table 3.2. Analyzed nutrients for starter (d 0-14) feed samples[1]

Nutrient Name[2]	Treatment (Trt)								
	Trt 1 – 0.88% dLys	Trt 2 – 0.96% dLys	Trt 3 – 1.04% dLys	Trt 4 – 1.12% dLys	Trt 5 – 1.20% dLys	Trt 6 – 1.283% dLys	Trt 7 – 1.36% dLys	Trt 8 – 1.44% dLys	Trt 9 (Control)[3] – 1.28% dLys
	Avg[4]	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Lysine	1.05	1.15	1.23	1.25	1.40	1.37	1.57	1.64	1.49
Methionine	0.44	0.50	0.55	0.60	0.66	0.66	0.73	0.79	0.70
Cysteine	0.30	0.33	0.35	0.34	0.37	0.35	0.40	0.40	0.38
Tryptophan	0.23	0.25	0.26	0.28	0.30	0.30	0.33	0.35	0.32
Threonine	0.70	0.77	0.85	0.84	0.92	0.93	1.04	1.08	0.98
Isoleucine	0.78	0.85	0.90	0.91	1.01	1.00	1.14	1.17	1.08
Valine	0.88	0.94	1.01	1.02	1.12	1.11	1.27	1.30	1.20
Arginine	1.10	1.22	1.29	1.31	1.44	1.43	1.66	1.72	1.54
Taurine	0.16	0.17	0.15	0.16	0.15	0.15	0.14	0.14	0.14
Aspartic acid	1.66	1.82	1.95	1.96	2.20	2.18	2.51	2.60	2.37
Serine	0.71	0.79	0.82	0.82	0.90	0.90	1.01	1.05	0.95
Glutamic acid	3.06	3.32	3.49	3.52	3.85	3.82	4.28	4.40	4.12
Proline	1.02	1.05	1.08	1.12	1.20	1.20	1.29	1.33	1.26
Lanthionine	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.03
Glycine	0.73	0.78	0.83	0.83	0.91	0.89	1.02	1.05	0.97
Alanine	0.93	0.97	1.02	1.02	1.08	1.07	1.17	1.19	1.14
Leucine	1.54	1.64	1.71	1.71	1.84	1.82	2.00	2.04	1.95
Tyrosine	0.56	0.62	0.65	0.65	0.70	0.71	0.80	0.82	0.72
Phenylalanine	0.86	0.94	0.99	0.99	1.09	1.08	1.23	1.26	1.18
Hydroxylysine	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05
Ornithine	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02
Histidine	0.47	0.50	0.53	0.53	0.58	0.58	0.65	0.66	0.62
Gross energy (kcal/kg)	3463.51	3521.73	3550.80	3566.12	3566.26	3576.13	3600.46	3621.63	3588.69
Crude protein	16.79	18.14	19.18	20.10	21.49	22.61	24.13	25.50	23.07

[1]Feed samples were analyzed in duplicate at Missouri University labs. Columbia, MO. Official Methods of Analysis of AOAC International: Amino acid (AA) by Performic acid/acid hydrolysis (Cysteine and Methionine); AA by Enzymatic/alkaline hydrolysis (Tryptophan); AA by Hydrochloric acid (all other AA)
[2]W/W%
[3]Treatment (Trt) 9 was the control diet which was formulated to have 1.28% digestible lysine (dLys). In order to verify the mixing technique, Trt 9 was made and compared to Trt 6 which was the mixed diet formulated to contain 1.283% dLys
[4]Average of two analyzed samples/treatment

Table 3.3. Digestible lysine (dLys) requirements of Cobb MV × Cobb 500 male broilers from 0 to 14 days of age based on linear broken line, quadratic broken line, and exponential asymptotic models

Model	Response variable	Estimated dLys requirement	P-value	R^2
Linear broken line[1]	BWG[2]	1.172	<0.00001	0.808
	FCR[3]	1.293	<0.00001	0.924
Quadratic broken line[4]	BWG	1.299	<0.00001	0.819
	FCR	1.494	<0.00001	0.935
Exponential asymptotic[5]	BWG	1.290	<0.0001	0.726
	FCR	1.470	<0.0001	0.919

[1]Linear broken line model
[2]Body Weight Gain (kg)
[3]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[4]Qudratic broken line model
[5]Exponential asymptotic model, in which the dLys requirement was calculated by 95% of the asymptote

Table 3.4. The effect of varying digestible lysine (dLys) levels on d 0 to 7 Cobb MV × Cobb 500 male broiler performance

Treatment (Trt)	**d 7 Avg[1] BW (kg)**	**d 0-7 BWG[2] (kg)**	**d 0-7 Avg FI/bird[3] (kg)**	**d 0-7 FCR[4]**	**d 0-7 Percent Mortality[5]**
Trt 1 – 0.88% dLys	0.158[c]	0.113[c]	0.140	1.226[a]	2.143
Trt 2 – 0.96% dLys	0.168[b]	0.123[b]	0.142	1.173[b]	1.429
Trt 3 – 1.04% dLys	0.170[b]	0.124[b]	0.142	1.150[b]	2.597
Trt 4 – 1.12% dLys	0.179[a]	0.134[a]	0.146	1.095[c]	1.299
Trt 5 – 1.20% dLys	0.178[a]	0.132[a]	0.142	1.078[c]	0.649
Trt 6 – 1.283% dLys	0.179[a]	0.134[a]	0.143	1.071[c]	0.000
Trt 7 – 1.36% dLys	0.182[a]	0.137[a]	0.144	1.068[c]	1.299
Trt 8 – 1.44% dLys	0.179[a]	0.134[a]	0.141	1.063[c]	0.649
Trt 9 (Control) – 1.28% dLys	0.181[a]	0.136[a]	0.142	1.051[c]	0.714
Fisher's LSD[6]	0.0111	0.0111	-	0.0488	-
P-value[7]	<0.0001	<0.0001	0.3491	<0.0001	0.7590
SEM[8]	0.0018	0.0018	0.0018	0.0078	0.4674

[1]Average
[2]Body Weight Gain (kg)
[3]Feed Intake/bird (kg)
[4]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[5]Percent Mortality is based on a beginning pen number of 14 birds
[6]Fisher's Least Significant Difference
[7]Alpha set at $P \leq 0.05$
[8]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[a-c]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 3.5. The effect of varying digestible lysine (dLys) levels on d 0 to 11 Cobb MV × Cobb 500 male broiler performance

Treatment (Trt)	d 11 Avg[1] BW (kg)	d 0-11 BWG[2] (kg)	d 0-11 Avg FI/bird[3] (kg)	d 0-11 FCR[4]	d 0-11 Percent Mortality[5]
Trt 1 – 0.88% dLys	0.284[f]	0.239[f]	0.320[de]	1.312[a]	3.571
Trt 2 – 0.96% dLys	0.305[e]	0.259[e]	0.327[bcd]	1.271[b]	1.429
Trt 3 – 1.04% dLys	0.314[d]	0.268[d]	0.332[abc]	1.233[c]	3.247
Trt 4 – 1.12% dLys	0.327[c]	0.282[c]	0.336[a]	1.193[d]	1.948
Trt 5 – 1.20% dLys	0.336[ab]	0.291[ab]	0.332[ab]	1.145[e]	0.649
Trt 6 – 1.283% dLys	0.331[bc]	0.285[bc]	0.325[cde]	1.138[e]	0.000
Trt 7 – 1.36% dLys	0.333[abc]	0.288[abc]	0.327[bcde]	1.136[e]	1.299
Trt 8 – 1.44% dLys	0.336[ab]	0.290[ab]	0.319[e]	1.102[f]	0.649
Trt 9 (Control) – 1.28% dLys	0.338[a]	0.293[a]	0.328[abc]	1.112[f]	1.429
Fisher's LSD[6]	0.0154	0.0154	0.0166	0.0207	-
P-value[7]	<0.0001	<0.0001	0.0006	<0.0001	0.3276
SEM[8]	0.0025	0.0025	0.0027	0.0034	0.5036

[1]Average
[2]Body Weight Gain (kg)
[3]Feed Intake/bird (kg)
[4]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[5]Percent Mortality is based on a beginning pen number of 14 birds
[6]Fisher's Least Significant Difference
[7]Alpha set at $P \leq 0.05$
[8]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[a-g]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 3.6. The effect of varying digestible lysine (dLys) levels on d 0 to 14 Cobb MV × Cobb 500 male broiler performance

Treatment (Trt)	d 14 d Avg[1] BW (kg)	d 0-14 BWG[2] (kg)	d 0-14 Avg FI/bird[3] (kg)	d 0-14 FCR[4]	0-14 d Percent Mortality[5]
Trt 1 – 0.88% dLys	0.417[d]	0.371[d]	0.517[b]	1.385[a]	4.286
Trt 2 – 0.96% dLys	0.449[c]	0.404[c]	0.537[a]	1.332[b]	2.857
Trt 3 – 1.04% dLys	0.460[c]	0.415[c]	0.536[a]	1.289[c]	3.247
Trt 4 – 1.12% dLys	0.481[b]	0.435[b]	0.542[a]	1.240[d]	1.948
Trt 5 – 1.20% dLys	0.499[a]	0.454[a]	0.540[a]	1.190[e]	0.649
Trt 6 – 1.283% dLys	0.498[a]	0.452[a]	0.531[a]	1.173[ef]	0.649
Trt 7 – 1.36% dLys	0.503[a]	0.458[a]	0.530[a]	1.158[fg]	1.299
Trt 8 – 1.44% dLys	0.498[a]	0.452[a]	0.516[b]	1.135[h]	0.649
Trt 9 (Control) – 1.28% dLys	0.508[a]	0.462[a]	0.531[a]	1.147[gh]	1.429
Fisher's LSD[6]	0.0281	0.0282	0.0269	0.0180	-
P-value[7]	<0.0001	<0.0001	<0.0001	<0.0001	0.2436
SEM[8]	0.0045	0.0045	0.0043	0.0029	0.5197

[1]Average
[2]Body Weight Gain (kg)
[3]Feed Intake/bird (kg)
[4]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[5]Percent Mortality is based on a beginning pen number of 14 birds
[6]Fisher's Least Significant Difference
[7]Alpha set at $P \leq 0.05$
[8]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[a-g]Values within columns with different superscripts differ significantly ($P<0.05$)

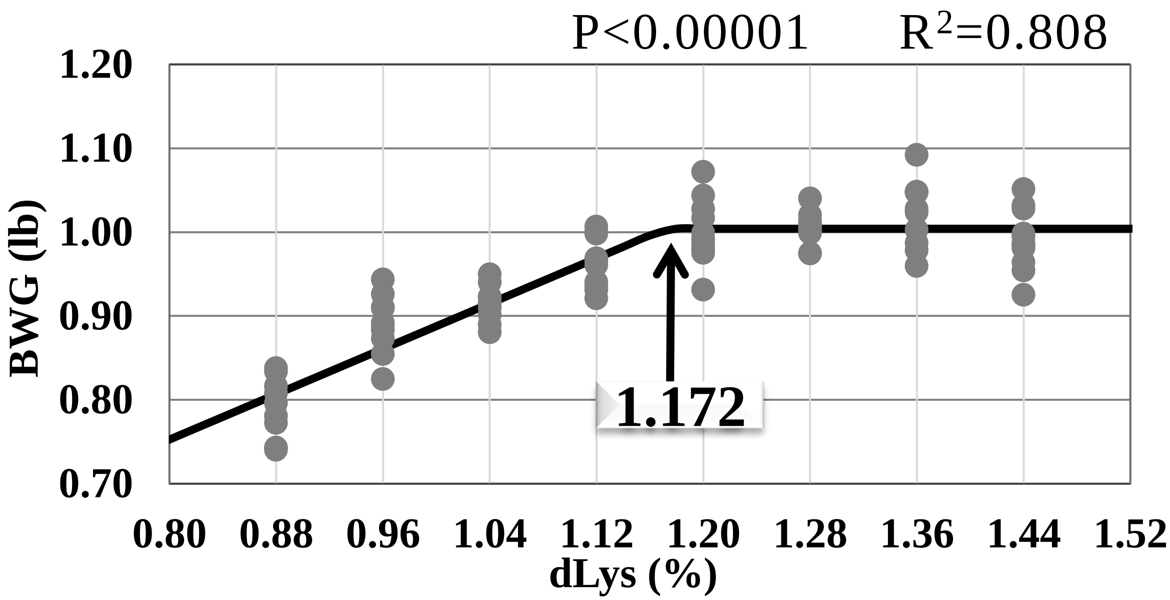

Figure 3. 1. Digestible lysine (dLys) requirements of Cobb MV × Cobb 500 male broilers from 0 to 14 days of age based on Linear broken line (LBL) model and body weight gain (BWG)

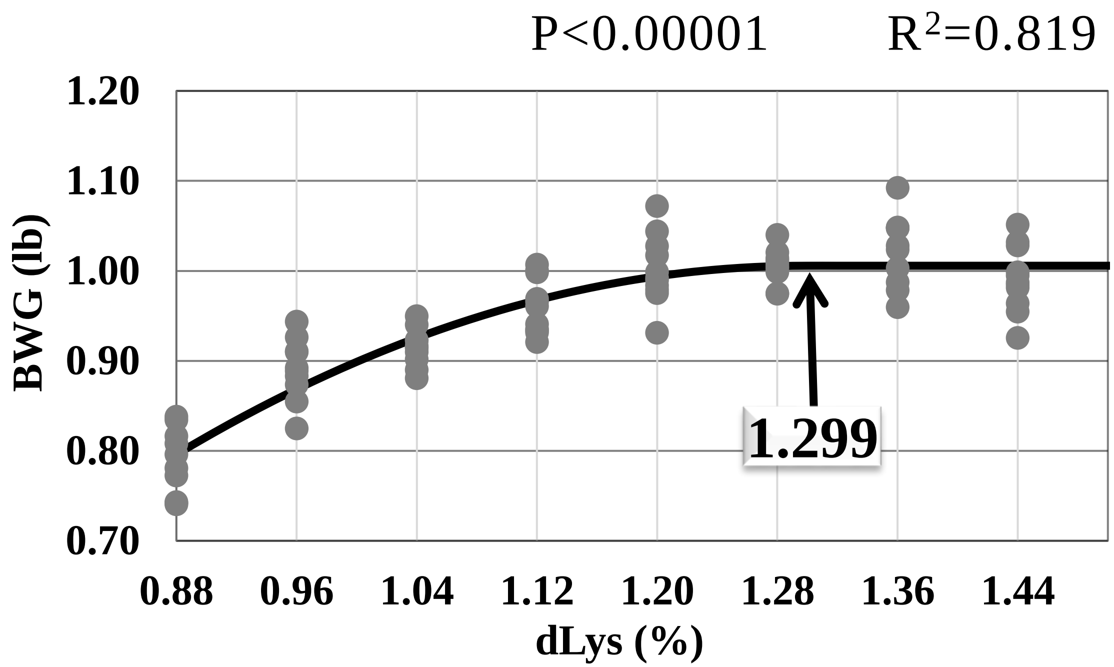

Figure 3. 2. Digestible lysine (dLys) requirements of Cobb MV × Cobb 500 male broilers from 0 to 14 days of age based on Quadratic broken line (QBL) model and body weight gain (BWG)

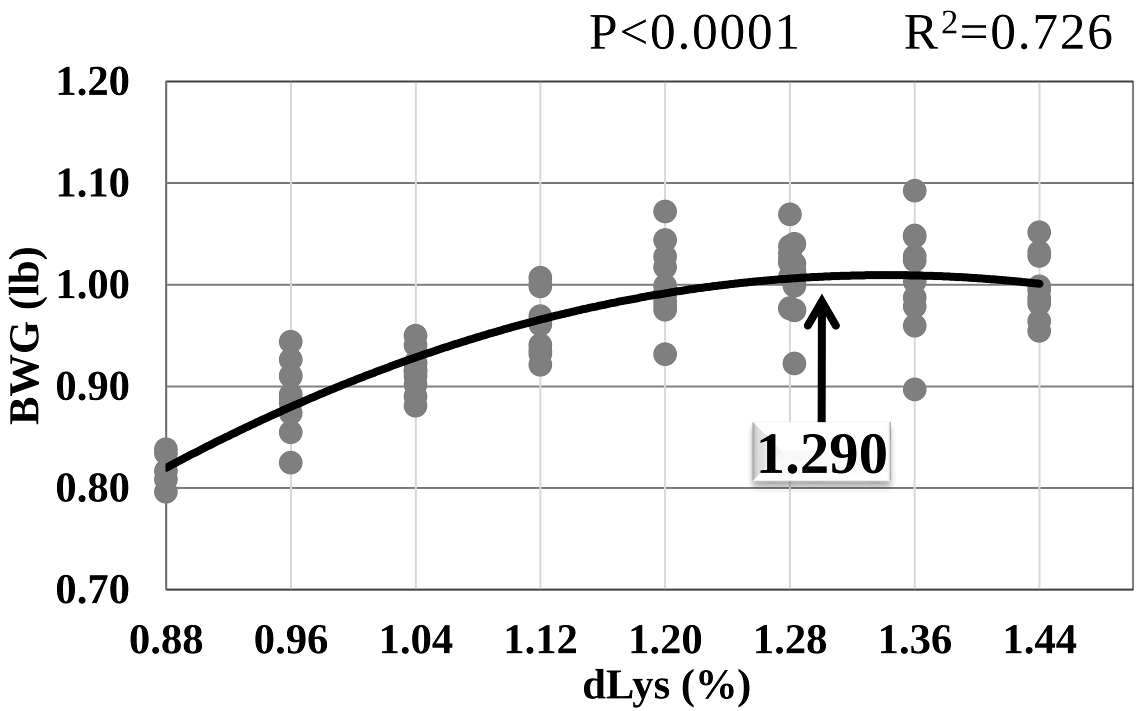

Figure 3. 3. Digestible lysine (dLys) requirements of Cobb MV × Cobb 500 male broilers from 0 to 14 days of age based on Exponential asymptotic (EA) model and body weight gain (BWG)[1]

[1]The dLys requirement was calculated by 95% of the asymptote, vertex: 1.36, 1.01

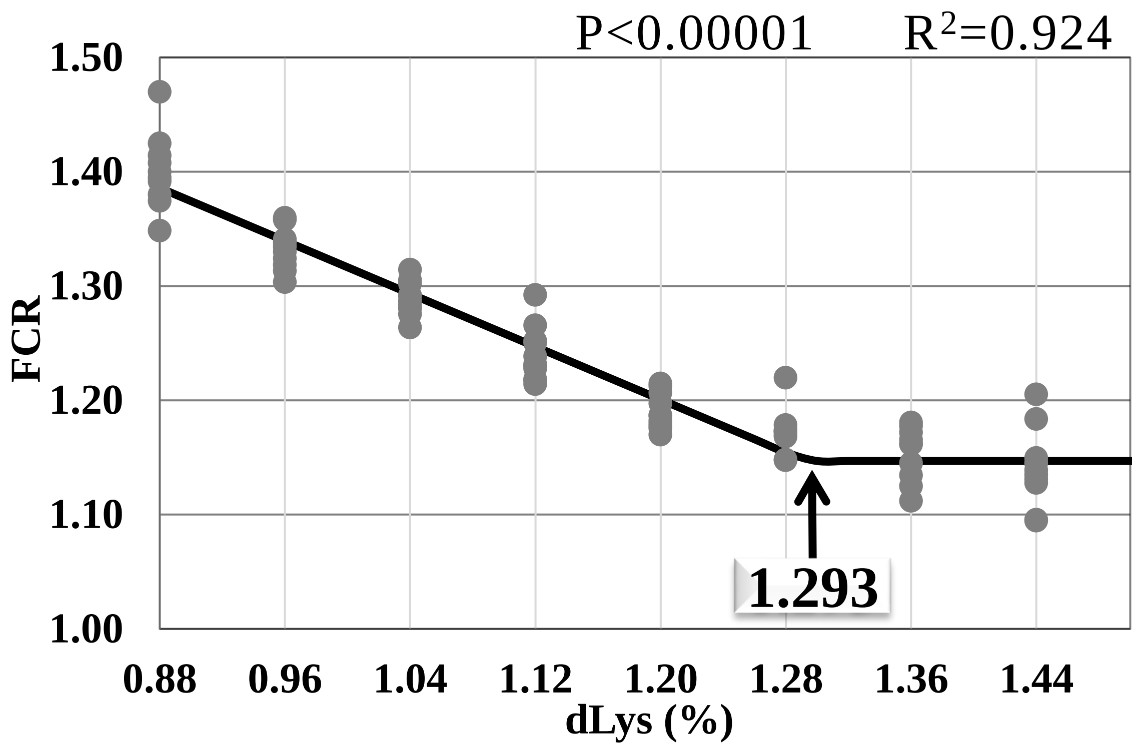

Figure 3. 4. Digestible lysine (dLys) requirements of Cobb MV × Cobb 500 male broilers from 0 to 14 days of age based on Linear broken line (LBL) model and feed conversion ratio (FCR)

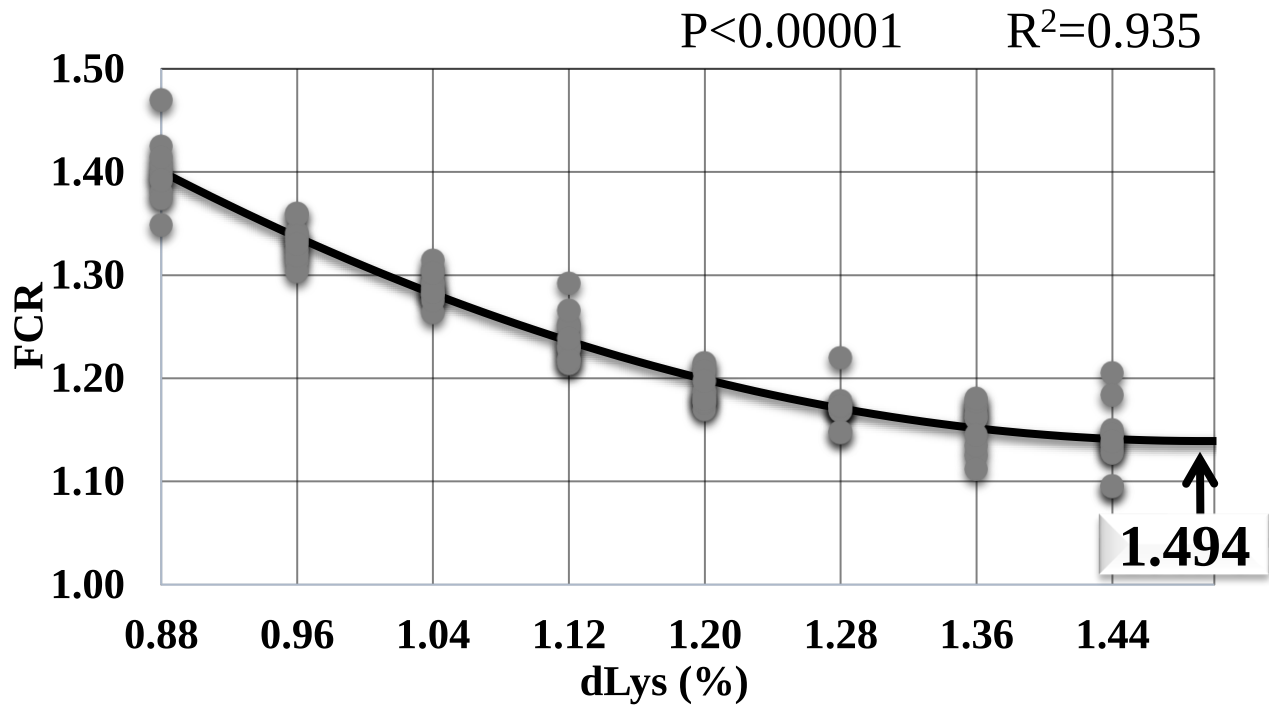

Figure 3. 5. Digestible lysine (dLys) requirements of Cobb MV × Cobb 500 male broilers from 0 to 14 days of age based on Quadratic broken line (QBL) model and feed conversion ratio (FCR)

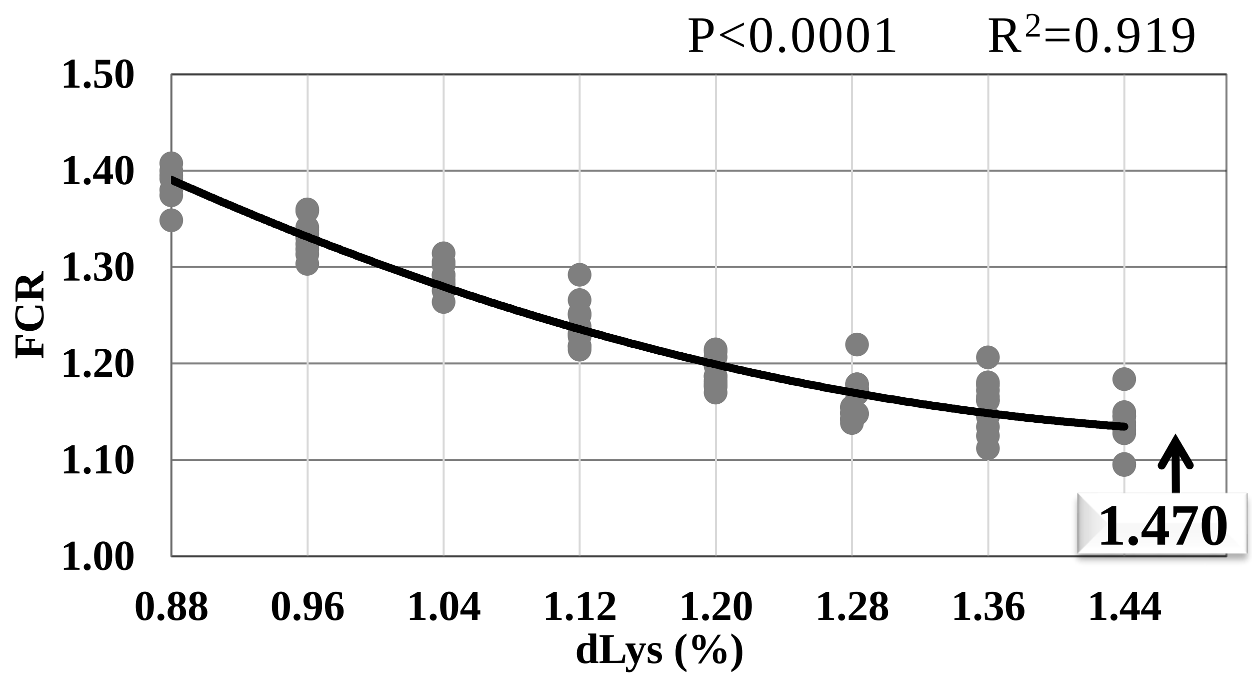

Figure 3. 6. Digestible lysine (dLys) requirements of Cobb MV × Cobb 500 male broilers from 0 to 14 days of age based on Exponential asymptotic (EA) model and feed conversion ratio (FCR)[1]

[1]The dLys requirement was calculated by 95% of the asymptote, vertex: 1.55, 1.13

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CHAPTER IV

THE CARRYOVER EFFECT OF FEEDING VARYING STARTER DIGESTIBLE LYSINE TO COBB MV × COBB 500 MALE BROILERS ON GROWTH PERFORMANCE, PROCESSING, AND ECONOMIC RESPONSE

Summary

Increasing digestible lysine (dLys) levels of diets may be effective in the starter phase if overall performance and economic benefits are realized throughout a complete grow-out period. Therefore, the objective of this study was to evaluate the carryover effect of varying dLys levels from d 0-14 to Cobb MV × Cobb 500 males on growth performance, yield, and economic response during a 42 d grow-out. Two basal diets were formulated: Treatment (Trt) 1 = 0.88% dLys and Trt 8 = 1.44% dLys. The other 6 experimental diets ranged between 0.96 to 1.44% dLys in increments of 0.08%, which were obtained by blending different proportions of Trts 1 and 2. In addition, a control diet (Trt 9 = 1.28% dLys) was made to verify the blending technique. Diets were provided to males randomly distributed in 96 pens from d 0-14. Common grower (1.05% dLys) and finisher (0.95% dLys) diets were provided from d 15-28 and 28-42, respectively. This study utilized a randomized complete block design (RCBD) with 9 treatments and 14 chicks/pen (0.08 m^2/bird). Benefits in body weight (BW) and BW gain (BWG) were found at d 41 when birds were fed ≥1.12% dLys during the starter period. Feeding starter dLys of 1.20% had some improvements in d 42 processing weight and the greatest financial return. However,

no significant differences were observed for processing yields at d 42. Further research should evaluate the response of Cobb MV × Cobb 500 female broilers to varying dLys levels and at other feeding phases.

Description of the Problem

The shift in demand of the whole carcass towards cut-up and further processed poultry meat by the early 1980s, as well as its increased consumer demand has resulted in changes to the poultry industry [1]. In an effort to meet this demand, primary breeding companies are constantly striving to select genetic traits that maximize muscle accretion and increase growth rate. Concurrently, nutritionists have been studying feeding strategies and regimes to meet the modern broilers' nutritional requirements and optimize broiler performance and economic return.

In 2017, a new broiler breeder product was introduced to the market by Cobb-Vantress [2], resulting in the production of a new commercial broiler strain, the Cobb MV × Cobb 500 [3]. Because literature has reported that several factors, including strain and age, can influence a bird's nutritional needs, there is a need for research on the nutritional specifications of each new commercial strain produced.

Among nutritional specifications, determining the proper level of digestible amino acids (AA) is important due to their essential role in muscle development. In addition, lysine (Lys) is vital for breast meat yield [4], and an increase in breast meat yield was previously reported when feeding high total Lys throughout production [5, 6]; however, this feeding strategy may not always be feasible [4]. Additionally, previous research suggested that providing high total Lys during the starter period could impact breast yield at the end of the grow-out period [5], and this could be economically beneficial, as birds eat less during this phase than in subsequent phases [4]. Therefore, the objective of the current study was to evaluate the carryover effect of feeding different levels of dLys during the first 14 days of age to Cobb MV × Cobb 500 male broilers on d 0-41 growth performance and d 42 processing yield.

Materials and Methods

Broiler Management

In a previous companion study (see Chapter 3), day old male chicks (Cobb MV × Cobb 500) were obtained from a commercial hatchery [7] and randomly assigned to pens (96 pens; 14 birds/pen; 0.08 m^2/bird). Pen weights were equalized by block on d 0. All birds were provided feed and water *ad libitum* throughout the experimental period (d 0-42). Temperature and lighting schedules utilized were in accordance with the breeder recommendations [8].

Experimental Diet Preparations

For more accurate diet formulation, corn and soybean meal were scanned using Near Infrared (NIR) Spectroscopy [9] and analyzed for total AA content [10, 11]. Broilers were fed experimental diets which contained dLys levels ranging from 0.88% to 1.44%, with increments of 0.08%. To create these diets, a Low (Treatment (Trt) 1) – 0.88% dLys) and a High (Trt 8 – 1.44% dLys) basal diet were manufactured and mixed in different ratios to make diets with intermediate levels of dLys (Trts 2 to 7). Furthermore, a control diet (Trt 9 – 1.28% dLys) was separately manufactured and used to verify the blending technique by comparing it with the mixed diet (Trt 6 – 1.28% dLys). These experimental diets were provided to the birds from d 0-14. Throughout the grower and finisher phases (d 14-28 and 28-41, respectively), broilers were fed common corn and soybean meal-based diets (Table 4.1). Prior to the processing process, feed samples were collected and sent to laboratory for analysis (Table 4.2) [11]. Further details regarding the facility information, batching, and feed manufacture process are reported in another publication (see Chapter 3).

Measured Variables

Live Performance

To calculate average body weight (BW), BW gain (BWG), average feed intake/bird (FI), and feed conversion ratio (FCR) adjusted for mortality, individual bird weights were collected from all pens on d 28 and 41 (Tables 4.3 and 4.4). All experimental procedures and bird handling were conducted according to the guidelines approved by Mississippi State University Institutional Animal Care and Use Committee and were in agreement with the Guide for the Care and Use of Agricultural Animals in Research and Teaching [12].

Processing Measurements

Three birds per pen (± 100 g avg. BW/pen; total of 288 birds) were weighed and tagged. Selected birds were removed from feed 10 h prior the processing at d 41. They were processed and deboned at the Mississippi State University Poultry Processing Plant on d 42, in which birds were hung by their feet in shackles on an automated line and stunned by an electric current running through a water bath. Next, by cutting their neck with a knife, birds were exsanguinated, and then submerged in hot water (52-66 °C) and afterward their feathers were removed by an automated plucking machine. Feet were manually cut at the hock joint, and carcasses were hung on a second automated line where heads, necks, and viscera were mechanically removed.

Abdominal fat pads were manually removed and kept for weight recording. Next, hot carcasses were removed from the processing line, to obtain the weights of abdominal fat pad and carcasses. Then, hot carcasses were chilled in water and ice for 3 hours (≤4°C). Each carcass was then deboned on a stationary line by 1 of 3 trained people, and the weights of boneless skinless breast (pectoralis major), tender (pectoralis minor), thigh, drumstick, and wing were recorded. Yield data was calculated relative to d 41 live BW, as well as d 42 carcass weight (Tables 4.5-4.7).

Economic Analysis

To determine the efficiency of increasing dLys levels in the starter, additional economic analysis was performed (Table 4.8); in which the potential gross chicken part values (in cents), the diet cost, the production cost per bird (in cents and dollar), and the gross profit/bird (in cents and dollar) for each dLys level were calculated based on chicken part values in the market [13], FI and processing data from the current study, and feed ingredient prices from Feedstuffs and USDA [14, 15]. Similar to Chapter 2, the economic analysis was obtained by the following equations:

Potential gross chicken part values (cents) = Processing data (chicken parts wt in kg) * Chicken part value in the market (cents) (4.1)

Total potential gross chicken part value/bird (cents) = sum of all potential gross chicken part values/bird (4.2)

Total feed cost/bird (cents) = Average feed intake (kg) * Feed cost (cents/kg) (4.3)

Total feed cost/bird (dollars) = Total feed cost/bird (cents)/100 (4.4)

Gross bird profit (cents) = Total potential gross profit/bird (cents) – Total feed cost/bird (cents) (4.5)

$$\text{Gross bird profit (dollars)} = \text{Gross bird profit (cents)}/100 \quad (4.6)$$

Statistical Analysis

In the current study, a randomized complete block design (RCBD) was utilized for growth performance and processing parameters, in which dietary treatments had 11 replicate floor pens (Trts 3-8) or 10 replicate floor pens (Trts 1, 2, and 9). Each floor pen with 14 birds (0.08 m^2/bird) was considered as an experimental unit; and the experimental period was from d 0-42. Growth performance measures and processing parameters were analyzed using the GLM option in SAS [16]. P-value significance was set as ≤ 0.05 and significant treatment means were further explored with Fisher's Least Significant Differences.

Results and Discussion

Broiler Performance

In a previous companion study (Chapter 3), overall results for starter period demonstrated that the dLys requirements varied among statistical models and response variables. Also, birds fed dLys levels of ≥1.20% had greater d 14 BW and d 0-14 BWG when compared to those fed ≤1.12% dLys. Data from the current study demonstrate an improvement in d 28 BW and d 0-28 BWG when feeding starter dLys levels of 1.12% or greater; broilers fed starter dLys of 1.20 and 1.44% had the highest BWG in comparison to those fed 0.88% dLys during the starter phase ($P<0.0001$; Table 4.3). Overall data (d 0-41) showed that broilers receiving starter dLys of 1.20% had the highest BW and BWG than those fed 0.88, 0.96, and 1.04% starter dLys ($P=0.0262$ and $P=0.0261$, respectively; Table 4.4). Broilers fed starter dLys of 1.12 and 1.28% (Trt 9 – Control diet), 1.283, 1.36, and 1.44% performed similar in terms of d 0-41 BW and BWG.

Data (d 0-28) showed that birds receiving starter diets formulated to 0.88% dLys had lowest FI when compared to birds fed starter diets formulated to 0.96, 1.20, 1.28, 1.283, 1.36, and 1.44% dLys; with broilers fed a starter dLys of 1.04 and 1.12% performing similar (P=0.0005; Table 4.3). Birds that were fed starter diets formulated to 1.20, 1.36, and 1.44% dLys consumed more feed than those fed 0.88 and 1.04% dLys during the starter phase. In addition, d 0-41 data demonstrated the lowest FI when birds were fed starter dLys of 0.88% compared to those fed starter dLys of 0.96, 1.04, 1.12, 1.28, and 1.283% (P=0.0259; Table 4.4). Starter diets formulated to 1.20% dLys had the highest FI when compared to broilers fed diets formulated to 0.88 and 1.04% starter dLys, in which broilers that were fed starter dLys of the remaining levels had similar overall feed consumption. In partial agreement with our results, it was previously reported that feeding higher levels of total Lys from d 1 to 18 increased FI at d 0-41, as well as 0-56; however, it did not affect FI at d 21 [17].

In addition, no significant difference was observed for FCR throughout the study (P>0.05; Tables 4.3 and 4.4). Similar to the current study, a previous study conducted by Kidd and Fancher [18] reported that varying levels of Lys from d 1 to 18 in two different experiments did not affect FCR at d 41 and 42. Furthermore, feeding diets formulated to ≤1.04% dLys during the starter phase reduced the percent mortality at 28, while feeding starter diets formulated to ≤0.96% dLys lowered the percent mortality at d 41 (P=0.0146 and P=0.0288, respectively; Tables 4.3 and 4.4). Unlike the current study, overall mortality was not affected by varying levels of total Lys from d 1 to 18 in two experiments using male Ross × Ross 508 broilers [18].

Processing

No significant difference was observed for processing yield at d 42 (P>0.05; Tables 4.5 and 4.6). This result is in partial agreement with a study conducted by Kidd et al. [19], in which no significant difference was observed for wing and drumstick yields (relative to d 35 live BW). However, they found that carcass, abdominal fat pad, total breast, and thigh yield (relative to d 35 live BW) were affected by varying AA density. Kidd et al [19] concluded that there was an improvement in d 49 breast meat yield of approximately 4.5% when increasing AA density during the starter phase (d 0-14).

Results of d 42 processing demonstrated no significant difference for drumstick, thigh, and abdominal fat pad weights (P>0.05; Table 4.7). Similar to the present study, it was previously reported that feeding different AA density regimes did not affect abdominal fat weight [20]. Additionally, data showed that broilers fed 1.20% starter dLys had greater tender weight when compared to broilers fed ≤ 1.12, 1.28 (Trt 9 – Control diet), and 1.283% starter dLys (P=0.0149; Table 4.7); and feeding starter dLys levels of ≥ 1.20% increased wing weight (P=0.0030; Table 4.7).

In addition, there was an improvement in average live weight of birds selected for processing, which was in a similar pattern to that of d 41 average live BW (P=0.0262; Table 4.4) and carcass weight, when broilers were fed diets formulated to 1.20% starter dLys as compared to those fed diets formulated to 0.88 and 1.04% starter dLys (P=0.0420 and P=0.0362 respectively; Tables 4.5 and 4.6). Birds receiving 0.96, 1.12, 1.28, 1.283, 1.36, and 1.44% starter dLys had similar performance (Tables 4.5 and 4.6). Additionally, an improvement in breast weight was observed when birds were fed with starter dLys of 1.20 and 1.36% as compared to those fed 0.88 and 1.04% starter dLys (P=0.0236; Table

4.7). Feeding 0.96, 1.12, 1.28, 1.283, and 1.44% dLys during the starter phase resulted in similar breast weight. Literature has demonstrated that feeding higher dietary Lys during the starter phase improved breast meat yield [5]. In agreement with the current study, improvements in carcass (at d 41 and 56) and breast (at d 41) weights were previously reported when feeding diets formulated to a high Lys level (1.35 vs. 1.20% total Lys) during the starter phase (d 0-21). However, they did not observe the same improvement for carcass and breast meat yields [17]. Also, it is important to mention that their starter phase was longer than the feeding phase in the current study (d 0-14).

Economic Analysis

At d 42, birds fed the diet formulated to 0.88% dLys during the starter phase had the lowest potential cost savings/gross profit per bird, while those fed the diet formulated to 1.20% starter dLys demonstrated the highest potential cost savings/gross profit per bird, with an increase of $0.34 in potential gross chicken part value (Table 4.8). However, it is essential to mention that economic analysis was calculated during a specific time (July of 2017). Since ingredient prices and chicken part values in the market have been volatile, it is important to constantly reevaluate the relationship between feed costs and processing data [21]. Although reaching the nutritional recommendations for broilers allows for proper growth, determining the optimal AA level for maximum broiler response depends on the company's production goal and broiler strain [22].

Summary and Future Direction

Data exhibited improvements in d 41 BW and d 0-41 BWG when feeding ≥1.12% starter dLys. Also, benefits in d 42 processing weight and economic return were observed when feeding d Lys level of 1.20% during the starter phase, which is close to what is reported in the broiler performance & nutrition supplement manual (1.18% dLys at d 0-11) [23]. In order to optimize the performance of this new broiler cross, future research should evaluate the impact of feeding varying dLys to Cobb MV × Cobb 500 female broilers and at other feeding phases.

Conclusions and Applications

1. Performance data demonstrated that feeding ≥1.12% dLys in the starter phase improved d 28 and 41 BW, as well as d 0-28 and 0-41 BWG of Cobb MV × Cobb 500 male broilers. In addition, increasing dLys during the starter phase decreased d 28 and 41 percent mortality, and increased FI at d 28 and 41.

2. While no significant differences were observed for d 42 processing yield, d 42 data demonstrated improvements in weights of carcass, breast, tender, and wing when feeding starter dLys level of 1.20%.

3. Based on the economic analysis using data from this study and current market prices for meat and feed, these data demonstrated that feeding Cobb MV × Cobb 500 male broilers a starter diet formulated to 1.20% dLys was the most profitable (in combination with feeding 1.05% dLys in the grower phase and 0.95% dLys in the finisher phase).

Table 4.1. Diet formulations for grower (d 14-28) and finisher (d 28-41) phases[1]

Ingredient Name	Common diet	
	Grower (d 14-28)	Finisher (d 28-41)
Corn	65.30	66.80
Soybean meal (48% CP)	29.10	26.90
Soybean oil	2.59	3.54
Defluorinated phosphate	1.21	1.00
Calcium carbonate	0.56	0.54
Salt, NaCl	0.20	0.23
L-Lysine HCl	0.13	0.08
L-Threonine	0.08	0.06
DL-Methionine	0.24	0.21
Phytase[2]	0.01	0.01
Sodium S-Carb	0.15	0.15
Vitamin-trace mineral	0.25	0.25
Selenium premix 0.06%	0.02	0.02
Choline Cl-70%	0.07	0.08
Antibiotic[3]	0.05	0.05
Coccidiostat[4]	0.03	0.03
Nutrient Name	**Calculated Nutrients (%)[5]**	
AME (kcal/kg)	3086.47	3170.25
Crude protein (%)	19.50	18.50
Crude fat (%)	4.80	5.70
Linoleic acid (%)	1.35	1.37
Calcium (%)	0.84	0.76
Total phosphorus (%)	0.58	0.53
Available phosphorus (%)	0.42	0.38
Sodium (%)	0.20	0.20
Potassium (%)	0.77	0.73
Chloride (%)	0.20	0.21
Na+K-Cl (mEq/kg)	228.00	216.00
Digestible lysine (%)	1.05	0.95
Digestible methionine (%)	0.52	0.48
Digestible methionine + Digestible cysteine (%)	0.80	0.74
Digestible tryptophan (%)	0.20	0.19
Digestible threonine (%)	0.69	0.65
Digestible isoleucine (%)	0.74	0.70
Digestible valine (%)	0.82	0.78
Digestible arginine (%)	1.17	1.11
Choline (mg/kg)	1543.24	1543.24

[1]All birds were fed with a common diet on grower (d 14-28) and finisher (d 28-41) phases
[2]Quantum Blue (*E.Coli* phytase). AB Vista, Plantation, FL.
[3]BMD-50 (bacitracin methylene disalicylate). Zoetis, Parsippany, NJ.
[4]Nicarb 25% (Nicarbazin). Phibro, Teaneck, NJ.
[5]Values are calculated based on the nutrient composition of corn and soybean meal

Table 4.2. Analyzed nutrients for grower (d 14-28) and finisher (d 28-41) feed samples[1]

Nutrient Name[2]	Common diet	
	Grower (d 14-28)	Finisher (d 28-41)
	Avg[3]	Avg
Lysine	1.16	1.07
Methionine	0.52	0.49
Cysteine	0.32	0.31
Tryptophan	0.24	0.23
Threonine	0.79	0.74
Isoleucine	0.85	0.87
Valine	0.91	0.87
Arginine	1.18	1.14
Taurine	0.20	0.20
Aspartic acid	1.83	1.74
Serine	0.79	0.78
Glutamic acid	3.32	3.23
Proline	1.08	1.09
Glycine	0.77	0.75
Alanine	0.95	0.95
Leucine	1.64	1.61
Tyrosine	0.61	0.60
Phenylalanine	0.96	0.92
Hydroxylysine	0.04	0.05
Ornithine	0.01	0.01
Histidine	0.49	0.47
Hydroxyproline	0.03	0.02
Gross energy (kcal/kg)	4079.43	4121.70
Crude protein	19.31	18.60

[1]Feed samples were analyzed in duplicate at Missouri University labs. Columbia, MO. Official Methods of Analysis of AOAC International: Amino acid (AA) by Performic acid/acid hydrolysis (Cysteine and Methionine); AA by Enzymatic/alkaline hydrolysis (Tryptophan); AA by Hydrochloric acid (all other AA)
[2]W/W%
[3]Average of two analyzed samples/treatment

Table 4.3. The carryover effect of varying digestible lysine (dLys) levels during the first 14 days of age on d 0-28 Cobb MV × Cobb 500 male broiler performance[1]

dLys level (%) fed in starter phase (d 0-14)	d 28 Avg[2] BW (kg)	d 0-28 BWG[3] (kg)	d 0-28 Avg FI/bird[4] (kg)	d 0-28 FCR[5]	d 0-28 Percent Mortality[6]
Trt 1 – 0.88	1.523[c]	1.478[c]	2.166[c]	1.437	7.143[a]
Trt 2 – 0.96	1.571[b]	1.526[b]	2.220[ab]	1.442	4.286[ab]
Trt 3 – 1.04	1.569[bc]	1.523[bc]	2.189[bc]	1.437	3.247[bc]
Trt 4 – 1.12	1.587[ab]	1.541[ab]	2.211[abc]	1.432	2.597[bc]
Trt 5 – 1.20	1.627[a]	1.581[a]	2.259[a]	1.431	0.649[c]
Trt 6 – 1.283	1.604[ab]	1.558[ab]	2.226[ab]	1.430	0.649[c]
Trt 7 – 1.36	1.609[ab]	1.563[ab]	2.245[a]	1.425	1.948[bc]
Trt 8 – 1.44	1.626[a]	1.581[a]	2.253[a]	1.422	1.299[bc]
Trt 9 (Control) – 1.28	1.599[ab]	1.553[ab]	2.229[ab]	1.422	1.429[bc]
Fisher's LSD[7]	0.0466	0.0466	0.0519	-	3.6136
P-value[8]	<0.0001	<0.0001	0.0005	0.0920	0.0149
SEM[9]	0.0165	0.0166	0.0184	0.0064	1.2832

[1]A common grower diet was fed to all birds from d 14-28 and this is a carryover effect of feeding diets varying dLys levels from d 0-14
[2]Average
[3]Body Weight Gain (kg)
[4]Feed Intake/bird (kg)
[5]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[6]Percent Mortality is based on a beginning pen number of 14 birds
[7]Fisher's Least Significant Difference
[8]Alpha set at $P \leq 0.05$
[9]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[a-c]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 4.4. The carryover effect of varying digestible lysine (dLys) levels during the first 14 days of age on d 0-41 Cobb MV × Cobb 500 male broiler performance[1]

dLys level (%) fed in starter phase (d 0-14)	d 41 Avg[2] BW (kg)	d 0-41 BWG[3] (kg)	d 0-41 Avg FI/bird[4] (kg)	d 0-41 FCR[5]	d 0-41 Percent Mortality[6]
Trt 1 – 0.88	2.431^{d}	2.385^{d}	4.074^{c}	1.660	9.286^{a}
Trt 2 – 0.96	2.528^{cd}	2.483^{cd}	4.161^{abc}	1.632	4.286^{b}
Trt 3 – 1.04	2.542^{bcd}	2.497^{bcd}	4.124^{bc}	1.622	4.545^{b}
Trt 4 – 1.12	2.557^{abc}	2.512^{abc}	4.220^{abc}	1.627	5.844^{ab}
Trt 5 – 1.20	2.665^{a}	2.620^{a}	4.294^{a}	1.632	1.948^{b}
Trt 6 – 1.283	2.577^{abc}	2.532^{abc}	4.188^{abc}	1.652	1.299^{b}
Trt 7 – 1.36	2.564^{abc}	2.518^{abc}	4.288^{ab}	1.623	5.195^{ab}
Trt 8 – 1.44	2.648^{ab}	2.603^{ab}	4.263^{ab}	1.631	1.948^{b}
Trt 9 (Control) – 1.28	2.572^{abc}	2.526^{abc}	4.180^{abc}	1.631	2.857^{b}
Fisher's LSD[7]	0.1152	0.1153	0.1643	-	4.5878
P-value[8]	0.0262	0.0261	0.0259	0.7916	0.0288
SEM[9]	0.0409	0.0409	0.0582	0.0120	1.6291

[1]Common grower and finisher diets were fed to all birds from d 14-41 and this is a carryover effect of feeding diets varying dLys levels from d 0-14
[2]Average
[3]Body Weight Gain (kg)
[4]Feed Intake/bird (kg)
[5]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[6]Percent Mortality is based on a beginning pen number of 14 birds
[7]Fisher's Least Significant Difference
[8]Alpha set at $P \leq 0.05$
[9]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
$^{a-c}$Values within columns with different superscripts differ significantly ($P<0.05$)

Table 4.5. The carryover effect of varying digestible lysine (dLys) during the first 14 days of age on d 42 processing characteristics reported as average yield relative to d 41 live weight[1]

dLys level (%) fed in starter phase (d 0-14)	Avg[2] d 41 BW[3] (kg)	Yield Relative to d 41 live BW (%)[4]						
		Carcass	Breast[5]	Tender[6]	Drumstick	Thigh	Wing	Fat Pad
Trt 1 – 0.88	2.484[c]	72.581	19.152	3.957	9.559	12.518	7.939	1.160
Trt 2 – 0.96	2.593[abc]	72.307	19.429	4.020	9.690	12.427	8.005	1.117
Trt 3 – 1.04	2.529[bc]	72.993	19.645	4.032	9.884	12.575	8.098	1.079
Trt 4 – 1.12	2.571[abc]	73.023	20.157	4.019	9.499	12.228	8.021	1.054
Trt 5 – 1.20	2.675[a]	72.907	20.250	4.158	9.540	12.358	8.126	1.106
Trt 6 – 1.283	2.580[abc]	72.418	19.673	3.950	9.527	12.365	8.145	1.177
Trt 7 – 1.36	2.638[ab]	72.789	19.985	4.059	9.631	12.313	7.949	1.025
Trt 8 – 1.44	2.641[ab]	72.748	20.035	3.958	9.397	12.282	8.045	1.104
Trt 9 (Control) – 1.28	2.578[abc]	73.053	20.331	4.036	9.612	12.314	8.128	1.186
Fisher's LSD[7]	0.1239	-	-	-	-	-	-	-
P-value[8]	0.0420	0.3904	0.2198	0.6035	0.4303	0.9769	0.2515	0.2771
SEM[9]	0.0440	0.0683	0.3263	0.0737	0.1436	0.2217	0.0690	0.0533

[1]Common grower and finisher diets were fed to all birds from d 14-41 and this is a carryover effect of feeding diets varying dLys levels from d 0-14
[2]Average
[3]Body Weight (kg)
[4]Yield relative to live BW (%)
[5]Breast refers to the pectoralis major
[6]Tender refers to the pectoralis minor
[7]Fisher's Least Significant Difference
[8]Alpha set at $P \leq 0.05$
[9]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[a-c]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 4.6. The carryover effect of varying digestible lysine (dLys) during the first 14 days of age on d 42 processing characteristics reported as average yield relative to carcass weight[1]

dLys level (%) fed in starter phase (d 0-14)	Carcass weight (kg)	Yield Relative to d 42 carcass weight (%)[2]					
		Breast[3]	Tender[4]	Drumstick	Thigh	Wing	Fat Pad
Trt 1 – 0.88	1.802[c]	26.400	5.470	13.152	17.213	10.974	1.564
Trt 2 – 0.96	1.877[abc]	27.037	5.546	13.328	16.959	11.073	1.524
Trt 3 – 1.04	1.846[bc]	26.901	5.526	13.543	17.222	11.100	1.482
Trt 4 – 1.12	1.877[abc]	27.612	5.507	13.014	16.755	10.993	1.444
Trt 5 – 1.20	1.951[a]	27.774	5.705	13.086	16.950	11.148	1.518
Trt 6 – 1.283	1.869[abc]	27.152	5.454	13.157	17.082	11.248	1.631
Trt 7 – 1.36	1.917[ab]	27.336	5.556	13.284	16.937	10.949	1.450
Trt 8 – 1.44	1.921[ab]	27.538	5.445	12.926	16.900	11.050	1.517
Trt 9 (Control) – 1.28	1.917[ab]	27.633	5.437	13.094	16.719	10.930	1.646
Fisher's LSD[5]	0.0894	-	-	-	-	-	-
P-value[6]	0.0362	0.3569	0.6925	0.5727	0.9534	0.4904	0.4055
SEM[7]	0.0317	0.3983	0.1003	0.2049	0.3033	0.1085	0.0762

[1]Common grower and finisher diets were fed to all birds from d 14-41 and this is a carryover effect of feeding diets varying dLys levels from d 0-14
[2]Yield relative to carcass weight (%)
[3]Breast refers to the pectoralis major
[4]Tender refers to the pectoralis minor
[5]Fisher's Least Significant Difference
[6]Alpha set at P≤0.05
[7]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[a-c]Values within columns with different superscripts differ significantly (P<0.05)

Table 4.7. The carryover effect of varying digestible lysine (dLys) during the first 14 days of age on d 42 processing characteristics reported as average weight[1]

dLys level (%) fed in starter phase (d 0-14)	Average weight (kg)[2]					
	Breast[3]	Tender[4]	Drumstick	Thigh	Wing	Fat Pad
Trt 1 – 0.88	0.480[c]	0.098[c]	0.237	0.305	0.197[c]	0.029
Trt 2 – 0.96	0.508[abc]	0.104[bc]	0.249	0.317	0.207[b]	0.029
Trt 3 – 1.04	0.498[bc]	0.102[bc]	0.250	0.318	0.205[bc]	0.027
Trt 4 – 1.12	0.518[ab]	0.103[bc]	0.244	0.314	0.205[bc]	0.027
Trt 5 – 1.20	0.543[a]	0.112[a]	0.254	0.330	0.217[a]	0.030
Trt 6 – 1.283	0.510[abc]	0.102[bc]	0.245	0.319	0.210[ab]	0.030
Trt 7 – 1.36	0.540[a]	0.108[ab]	0.259	0.332	0.214[ab]	0.029
Trt 8 – 1.44	0.531[ab]	0.105[abc]	0.245	0.323	0.212[ab]	0.029
Trt 9 (Control) – 1.28	0.521[ab]	0.102[c]	0.245	0.315	0.209[ab]	0.031
Fisher's LSD[5]	0.0371	0.0068	-	-	0.0091	-
P-value[6]	0.0236	0.0149	0.0920	0.3819	0.0030	0.5372
SEM[7]	0.0132	0.0024	0.0046	0.0071	0.0032	0.0015

[1]Common grower and finisher diets were fed to all birds from d 14-41 and this is a carryover effect of feeding diets varying dLys levels from d 0-14

[2]Yield relative to average weight (%)

[3]Breast refers to the pectoralis major

[4]Tender refers to the pectoralis minor

[5]Fisher's Least Significant Difference

[6]Alpha set at $P \leq 0.05$

[7]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean

[a-c]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 4.8. Potential gross bird profit or potential saving for each starter digestible lysine (dLys) level

Potential gross chicken part values[1] using processing data (chicken parts weight in kg) and chicken part values in the market (cents)[2]	dLys level (%) fed in starter phase (d 0-14)[3]								
	Trt 1 – 0.88	**Trt 2 – 0.96**	**Trt 3 – 1.04**	**Trt 4 – 1.12**	**Trt 5 – 1.20**	**Trt 6 – 1.283**	**Trt 7 – 1.36**	**Trt 8 – 1.44**	**Trt 9 (Control)[4] – 1.28**
Breast	160.78	170.21	166.71	173.70	182.06	170.21	166.71	177.81	174.61
Wing	85.71	90.04	89.06	89.26	94.38	90.04	89.06	92.21	90.63
Tender	43.43	45.83	45.03	45.63	49.23	45.83	45.03	46.23	44.83
Thigh	40.45	42.13	42.25	41.65	43.76	42.13	42.25	42.92	41.83
Drumstick	27.32	28.74	28.84	28.16	29.36	28.74	28.84	28.32	28.32
Total potential gross chicken part values/bird (cents)[5]	357.69	376.95	371.89	378.40	398.79	376.95	371.89	387.48	380.23
Total feed costs/bird (cents)[6]	94.85	97.18	97.38	98.78	102.22	100.47	101.25	101.65	98.01
Total feed costs/bird (dollars)[7]	0.949	0.972	0.974	0.988	1.022	1.005	1.013	1.017	0.980
Gross bird profit (profit processing-feed costs/bird; cents)[8]	262.85	279.77	274.52	279.61	296.57	276.48	270.65	285.83	282.22
Gross bird profit (profit processing-feed costs/bird; dollars; kg)[9]	2.629	2.798	2.745	2.796	2.966	2.765	2.707	2.858	2.822

[1]Potential gross chicken part values = Processing data (chicken parts wt in kg) * Chicken part value in the market (cents)
[2]Express Markets Incorporated (weekly report for July 7, 2017; 5-day average, Fort Wayne, IN. Chicken part prices (cents/kg): Breast = 335.09; Wings = 434.45; Tenderloins = 441.31; Thighs = 132.72; Drumsticks = 115.41)
[3]Nine dietary dLys levels were provided to birds during the first 14 days of age, and common grower and finisher diets were fed to all birds from d 14-41
[4]Treatment 9 was the control diet (1.28% starter dLys), which was made to compare to the mixed diet Trt 6 (starter 1.283% strater dLys)
[5]Total potential gross chicken part value/bird (cents) = sum of the potential gross chicken part values (breast, wings, tenders, thighs, and drumsticks) per bird
[6]Total feed cost/bird (cents) = Average feed intake (kg) * Feed cost (cents/kg; ingredient prices were based from Feedstuffs - Ingredient Market Prices and USDA - Feedstuffs Reports. Ingredient prices ($/ton): corn = $137.28; soybean meal = $361.76; deflourinated phosphate = $1,675; calcium carbonate = $233.62; salt = $59.51; soybean oil = $34.64; sodium S-carb = $537.78; vitamin-trace mineral = $1,715; selenium premix = $425.37; DL-methionine = $3,174; L-lysine = $1,829; L-threonine = $2,138; L-valine = $10,910; phytase = $9,147; bacitracin = $8,265; nicarbazin = $990)
[7]Total feed cost/bird (dollars) = Total feed cost/bird (cents) / 100
[8]Gross bird profit (cents) = Total potential gross profit/bird (cents) – Total feed cost/bird (cents)
[9]Gross bird profit (dollars; in kg) = Gross bird profit (cents) /100

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CHAPTER V

IMPACT OF FEEDING VARYING STARTER DIGESTIBLE LYSINE AND ENERGY LEVELS TO MALE COBB MV × COBB 500 BROILERS ON 42-DAY GROWTH PERFORMANCE AND PROCESSING

Summary

Previous research has shown that feeding high amino acid density (AAD) or increased apparent metabolizable energy (AME**)** improved broiler performance; though, the relationship between AAD and AME on broiler performance needs to be further explored. Therefore, the objective of the current study was to evaluate the impact of feeding varying digestible lysine (dLys) and AME levels from d 0-14 on performance and yield of 42-day old Cobb MV × Cobb 500 males. Starter diets were formulated to contain dLys of either 1.18 or 1.28% and AME levels of 2890, 2980, 3070, and 3160 kcal/kg. Common grower and finisher diets were provided for the remainder of grow-out. A 2×4 factorial arrangement of treatments was used, with d 0 BW as a covariant. On d 0-14, birds receiving 1.28% dLys had the lowest feed conversion ratio (FCR) corrected and uncorrected for mortality (uFCR). Birds receiving 2890 kcal/kg AME diets had the highest d 0-14 FCR when compared to birds fed other AME levels. Feeding 2980 kcal/kg AME diets resulted in higher d 0-14 FCR when compared to 3070 and 3160 kcal/kg AME diets. A dLys × AME interaction was observed for d 0-28 uFCR. Increasing starter AME levels from 2890 to 2980 kcal/kg improved d 0-28 uFCR, regardless of starter dLys levels. However, overall growth performance and processing was not affected by varying

starter dLys and AME. Further research should investigate similar feeding strategies, but in other feeding phases.

Description of the Problem

Feed costs represent the majority of the total broiler production cost, with the ingredients that provide amino acid (AA) and apparent metabolizable energy (AME) being the main contributors for this high cost [1]. Therefore, various feeding strategies have been evaluated in attempt to lower production costs and maximize performance. Literature has reported that feeding high AA density (AAD) regimens improved growth performance of broilers [2]. This is in agreement with a previous research conducted in our lab [3], where feeding high AAD diets demonstrated improvements in performance, yield, and economic return at d 32. In addition, it was previously stated that interactions between dietary levels of AA and AME can greatly affect broiler performance [1]. These data suggest that there may be an optimum AA level at a particular AME that may be beneficial. Providing a diet enhanced in nutritional profile during the starter and/or grower phase may be economically feasible by the end of grow-out due to the low amount of feed consumed during these feeding phases, as well as the fast growth rate during this period [4]. Among AA, lysine (Lys) is the reference AA used for the ideal protein concept, where all the other AA are calculated as a ratio to Lys [5].

Currently, there is no published data on the response of Cobb MV × Cobb 500 broilers to varying digestible lysine (dLys) and AME. Hence, the objective of the current study was to evaluate the impact of feeding two levels of dLys (1.18 and 1.28%) and four AME (2890, 2980, 3070, and 3160 kcal/kg) levels during the starter phase on d 0-14 growth performance, as well as the carryover effect of varying starter dLys and AME on 42-day performance and processing yield of male Cobb MV × Cobb 500 broilers.

Materials and Methods

Broiler Management

On d 0, Cobb MV × Cobb 500 male chicks were provided from a commercial hatchery [6], then weighed and randomly distributed into 96 pens (0.08 m^2/bird, 14 males/pen) in a solid-walled house with cool cell pads, a forced-air heating system, and cross ventilation. Each pen had a hanging-type feeder, three nipple drinkers, and used litter that was covered by fresh shavings. The temperature and lighting programs followed the breeder recommendations and were daily monitored [7]. The temperature at placement was 32.2°C and had a gradual decrease to 18.3°C on d 42. Birds were provided with 24 h of light during the first seven days of age, which was decreased to 20 h of light from d 7 to the end of the study. The intensity was set to 26.9 lux from d 0-10, having a gradual decrease to 2.7 lux on d 21, which was kept until d 42 [7]. In addition, bird mortality was collected at least twice a day. Feed and water were provided *ad libitum* from d 0-42, in which birds were fed with dietary treatments during the first 14 d of age (starter phase), and common grower and finisher diets thereafter (d 14-28 and 28-41, respectively).

Experimental Diet Preparations

Diet Formulation

Starter diets were formulated to two different levels of dLys (1.18 or 1.28%) and AME levels varying from 2890, 2980, 3070, to 3160 kcal/kg (Table 5.1). Corn and soybean meal were scanned using Near Infrared (NIR) Spectroscopy [8] and analyzed for nutrient content [9, 10] prior to formulation at each phase to be as precise as possible (Table 5.2). Common grower and finisher diets were formulated to 1.05% dLys + 3086.47 kcal/kg AME, and 0.95% dLys + 3170.25 kcal/kg AME, respectively (Tables 5.3 and 5.4).

Batching

Basal diets were individually manufactured at the Poultry Research Unit, Mississippi State University (Starkville, MS). Ingredients with inclusion <0.5% of the total diet, such as trace minerals, vitamins, and crystalline amino acids, were weighed and mixed to create a premix. A vertical screw mixer with 0.907-tonne capacity [11] was used to mix the macro ingredients (i.e. corn and soybean meal) and the appropriate premix of each diet for 5 minutes. Next, soybean oil was added to each basal diet and mixed for an additional 10 minutes to create a homogenous diet.

Feed Manufacture

All diets were transported and pelleted at the Poultry Research Unit, U.S. Department of Agriculture (Starkville, MS). The steam conditioned temperature was kept at 81°C (10 s) and incoming steam pressure of 262 kPa. The pelleting order for experimental diets occurred in order of increasing levels of AME at each dLys level, with diets formulated to 1.18% dLys being pelleted first, followed by 1.28% dLys. Flushing of whole corn grain was conducted between dLys levels to avoid cross contamination. Feed samples were collected after the cooler throughout each run and analyzed by a commercial laboratory [9, 10]. Starter feed was provided to birds as a crumble from d 0-14, while common grower and finisher diets were provided as pellets from d 14 to the end of the study.

Measured Variables

Live Performance

Performance data was obtained by measuring the weight of remaining feed and individual birds at d 14, 28, 35, and 41 to calculate the average body weight (BW), BW gain (BWG), average feed intake/bird (FI), and feed conversion ratio (FCR) corrected and uncorrected for mortality (uFCR). Animal handling and all procedures conducted in this current study followed the guidelines from the Mississippi State University Institutional Animal Care and Use Committee, which is in accordance with the Guide for the Care and Use of Agricultural Animals Research and Teaching [12].

Processing Measurements

One day prior to processing at the Mississippi State University Poultry Processing Plant, three birds per pen (± 100 g of average BW/pen; total of 288 males) were selected, weighed and tagged. Feed removal was conducted 10 h prior to processing. On the day of processing, tagged birds were hung by their feet on an automatic processing line and electronically stunned. Birds were then exsanguinated by cutting their necks with a knife. Next, broilers were submerged in hot water (52-66°C) to facilitate the removal of feathers, which was performed by an automated plucking machine with rubber fingers. Subsequently, chicken feet were cut at the hock joint, and carcasses were manually rehung on a second automated line. Each carcass had its head, neck, and viscera mechanically removed. Abdominal fat pad was manually removed and weighed. Hot carcasses were weighed and chilled in an ice bath for 3 hours (≤4°C), prior to deboning. Deboning was conducted on a stationary line where each carcass was deboned by 1 of 3 trained people. The weights of carcasses, boneless skinless breasts (pectoralis major), tenders (pectoralis minor), thighs, drumsticks, and wings were recorded to calculate processing yield (relative to live d 41 BW and d 42 carcass weight).

Statistical Analysis

A 2 × 4 factorial arrangement of treatments within a randomized complete block design (RCBD) was utilized, in which the d 0 BW was a covariant. A floor pen with 14 males was considered the experimental unit and each dietary treatment had 12 replicated floor pens. To analyze the data, the GLM procedure (two-way ANOVA) of the SAS [13] was performed, with significance level set as P-value ≤ 0.05, and treatment means were further explored with Tukey's range test.

Results and Discussion

Feed Analysis

Feed samples were analyzed for total AA profile, crude protein, and AME to confirm the assigned nutrient levels. The analyzed and the calculated values from each diet are displayed in Tables 5.1-5.4. These tables reveal similar results for the analyzed values to that of the calculated values.

Broiler Performance

No dLys × AME interactions nor differences for the main effects were observed for BW, BWG, FI, and percent mortality throughout the study, as well as d 0-41 FCR and uFCR (P>0.05; Tables 5.5-5.7). In addition, no significant difference for the main effect of dLys level was found for d 0-28 FCR (P>0.05; Table 5.6). Similar to these results, varying dietary levels of AA density (AAD) and AME did not affect percent mortality throughout the rearing period [1]. In contrast, a previous study evaluating the response of Cobb 700 straight-run broilers to different levels of AAD and AME found a significant interaction of AAD and AME for FI and BW at d 28, 35, 42, and 54 [1]. In that study, feeding high AAD and low AME (d 0-14: 1.25% dLys + 2987 kcal/kg AME; d 14-28: 1.14% dLys + 3085 kcal/kg AME; d 28-35: 0.98% dLys + 3130 kcal/kg AME; and d 35-54: 0.90% dLys + 3130 kcal/kg AME) diets resulted in lower FI and BW. However, when Cobb 700 broilers were fed diets with high AAD and AME (d 0-14: 1.25% dLys + 3042 kcal/kg AME; d 14-28: 1.14% dLys + 3140 kcal/kg AME; d 28-35: 0.98% dLys + 3185 kcal/kg AME; and d 35-54: 0.90% dLys + 3185 kcal/kg AME) similar FI and BW were obtained [1]. In disagreement with these results, literature has previously reported improvements in d 28 FCR of Cobb × Cobb 700 broilers when feeding higher AAD in the diets [1, 14].

In addition, significant differences were observed for the main effect of dLys and AME level for d 0-14 FCR and uFCR ($P<0.0001$; Table 5.5), in which feeding starter diets formulated to 1.28% dLys improved FCR, as well as uFCR. Additionally, birds receiving starter AME levels of 3070 and 3160 kcal/kg had the lowest FCR and uFCR, with those fed starter diets formulated to 2980 kcal/kg AME performing intermediate. Feeding a starter AME of 2890 kcal/kg resulted in the highest d 0-14 FCR and uFCR. These results are inconsistent with a previous study in which feeding higher AME (3042 vs. 2987 kcal/kg) to Cobb × Cobb 700 broilers increased d 14 FCR [1], perhaps because young birds need less AME and more protein as compared to their requirement at older age [1].

A significant dLys × AME interaction was observed for d 0-28 uFCR ($P=0.0275$; Table 5.6; Figure 5.1), in which there was a decrease in uFCR when birds were fed increasing starter AME levels for the diets formulated to 1.18% starter dLys. Also, feeding 1.18% dLys + 3160 kcal/kg AME during the starter phase yielded the lowest d 0-28 uFCR. A similar result was not found for birds fed starter diets formulated to 1.28% dLys with increased AME level. However, this interaction was lost by the end of the study (Table 5.7). Although previous data did not observe a significant AAD × AME interaction for d 28 FCR, they found a significant interaction for FCR at d 42, where there was an improvement in FCR when feeding high levels of AAD and AME to Cobb × Cobb 700 straight-run broilers [1]. In addition, a significant difference was observed for the main effect of AME for d 0-28 FCR, where feeding starter AME levels of 3070 and 3160 kcal/kg improved FCR as compared to those fed starter diets formulated to 2890 kcal/kg AME. Birds receiving 2980 kcal/kg AME during the starter phase had similar and intermediate performance ($P<0.0001$; Table 5.6).

Processing

Processing data demonstrated no significant dLys × AME interaction nor significance for the main effects for any measured variables ($P>0.05$; Tables 5.8-5.10). This result may be due to the fact that feeding different levels of dLys and AME from d 0-14 may not be long enough to see differences in overall performance. Additionally, it was previously suggested that high-yield broilers may need a higher Lys level in the final phase due to the increase in their pectoralis major size in proportion to their total body volume [2]. In disagreement, previous research reported an interaction of AAD and AME levels at d 55, where Cobb 700 straight-run broilers fed high AAD and low AME diets had the lowest weights of carcass, breast, wing, front half, and back half when compared to those fed the remaining diets [1]. In addition, they also found significance for the main effects of AAD and AME levels on processing parameters, in which feeding a higher AAD decreased the weights of drumstick, thigh, and fat, as well as decreased fat pad yield (relative to BW) and increased wing yield (relative to BW), while providing a higher AME had an opposite effect [1].

Summary and Future Direction

This study emphasizes the importance of evaluating the response of Cobb MV × Cobb 500 broilers to varying dLys and AME levels during the starter phase and their carry-over effects on d 42 growth performance and yield. Results for the main effect of dLys demonstrated that birds fed 1.28% dLys had the lowest d 0-14 FCR and uFCR. Feeding 3070 and 3160 kcal/kg AME diets during the starter phase resulted in the lowest d 0-14 FCR and uFCR. A significant dLys × AME interaction was observed for d 0-28 uFCR. Regardless of starter dLys levels, there was an improvement in d 0-28 uFCR when increasing starter AME levels from 2890 to 2980 kcal/kg. However, no significant dLys × AME interaction nor significance for the main effects were observed at the end of this study. Therefore, further research should investigate formulation strategies during these feeding phases and also evaluate the impact of varying dLys and AME levels on female Cobb MV × Cobb 500 broilers during various feeding phases.

Conclusion and Applications

1. A significant difference for the main effect of dLys was observed where Cobb MV × Cobb 500 male broilers fed 1.28% dLys during the starter phase had the lowest d 0-14 FCR and uFCR.
2. Significance for the main effect of AME was observed for FCR; feeding starter diets formulated to ≤3070 kcal/kg AME improved d 0-14 FCR, while feeding ≤2980 kcal/kg AME improved d 0-28 FCR.
3. A significant dLys × AME interaction was observed on d 0-28 uFCR, where a decrease in uFCR was found when increasing starter AME levels in the diets formulated to 1.18% starter dLys; broilers fed starter diets formulated to 1.18% dLys + 3160 kcal/kg

AME had the lowest uFCR. However, this interaction was lost by the end of the grow-out period, likely due to diet formulation strategies only provided in the starter phase.

4. Overall growth performance and processing data was not affected by dLys and/or AME; though, the current study's results may be different if other formulation metrics were utilized in the grower and finisher phases.

Table 5.1. Diet formulations for starter phase (d 0-14)[1]

Ingredient Name	1.18% dLys + 2890 kcal/kg AME	1.18% dLys + 2980 kcal/kg AME	1.18% dLys + 3070 kcal/kg AME	1.18% dLys + 3160 kcal/kg AME	1.28% dLys + 2890 kcal/kg AME	1.28% dLys + 2980 kcal/kg AME	1.28% dLys + 3070 kcal/kg AME	1.28% dLys + 3160 kcal/kg AME
Corn	60.60	58.50	56.50	54.40	57.50	55.50	53.50	51.40
Soybean meal (48% CP)	35.80	36.10	36.50	36.80	38.20	38.50	38.90	39.20
Soybean oil	0.48	2.19	3.90	5.61	1.00	2.70	4.41	6.12
Defluorinated phosphate	1.32	1.33	1.33	1.34	1.31	1.31	1.32	1.32
Calcium carbonate	0.55	0.55	0.54	0.54	0.55	0.54	0.54	0.53
DL-Methionine	0.29	0.29	0.29	0.30	0.35	0.35	0.35	0.35
L-Lysine HCL	0.10	0.10	0.09	0.08	0.15	0.15	0.14	0.14
L-Threonine	0.08	0.08	0.08	0.07	0.11	0.11	0.11	0.11
Phytase[2]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Salt, NaCl	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Sodium S-Carb	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin-trace mineral	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Selenium	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Choline Cl-60%	0.04	0.04	0.04	0.04	0.03	0.03	0.04	0.04
Antibiotic[3]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Coccidiostat[4]	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Nutrient Name	**Calculated Nutrients (%)[5]**							
AME (kcal/kg)	2890	2980	3070	3160	2890	2980	3070	3160
Crude protein (%)	21.50	21.50	21.50	21.50	22.50	22.50	22.50	22.50
Crude fat (%)	2.70	4.30	6.00	7.60	3.10	4.80	6.40	8.10
Linoleic acid (%)	1.30	1.30	1.20	1.20	1.20	1.20	1.20	1.10
Calcium (%)	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Total phosphorus (%)	0.63	0.63	0.62	0.62	0.63	0.63	0.63	0.63
Available phosphorus (%)	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Sodium (%)	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Potassium (%)	0.89	0.89	0.89	0.89	0.93	0.93	0.93	0.93
Chloride (%)	0.21	0.20	0.20	0.20	0.21	0.21	0.21	0.21
Na+K-Cl (mEq/kg)	264.80	265.60	266.40	267.20	272.20	273.00	273.80	274.60
Digestible lysine (%)	1.18	1.18	1.18	1.18	1.28	1.28	1.28	1.28
Digestible methionine (%)	0.59	0.59	0.59	0.59	0.66	0.66	0.66	0.66
Digestible methionine + Digestible cysteine (%)	0.89	0.89	0.89	0.89	0.96	0.96	0.96	0.96
Digestible tryptophan (%)	0.23	0.23	0.23	0.23	0.24	0.24	0.25	0.25
Digestible threonine (%)	0.77	0.77	0.77	0.77	0.83	0.83	0.83	0.83
Digestible isoleucine (%)	0.84	0.85	0.85	0.85	0.88	0.89	0.89	0.89
Digestible valine (%)	0.92	0.92	0.92	0.92	0.96	0.96	0.96	0.96
Digestible arginine (%)	1.34	1.34	1.34	1.35	1.40	1.41	1.41	1.41
Choline (mg/kg)	1543	1543	1543	1543	1543	1543	1543	1543

[1]Two different digestible lysine (dLys) levels and four different energy levels were used to create eight treatments: Trt 1 = 1.18% dLys + 2890 kcal/kg AME; Trt 2 = 1.18% dLys + 2980 kcal/kg AME; Trt 3 = 1.18% dLys + 3070 kcal/kg AME; Trt 4 = 1.18% dLys + 3160 kcal/kg AME; Trt 5 = 1.28% dLys + 2890 kcal/kg AME; Trt 6 = 1.28% dLys + 2980 kcal/kg AME; Trt 7 = 1.28% dLys + 3070 kcal/kg AME; Trt 8 = 1.28% dLys + 3160 kcal/kg AME

[2]Quantum Blue (*E.Coli* phytase). AB Vista, Plantation, FL.

[3]BMD-50 (Bacitracin methylene disalicylate). Zoetis, Parsippany, NJ.

[4]Nicarb 25% (Nicarbazin). Phibro, Teaneck, NJ.

[5]Values are calculated based on the results of nutrient composition of corn and soybean meal at Missouri University labs. Columbia, MO.

Table 5.2. Analyzed nutrients for starter (d 0-14) feed samples[1]

Nutrient Name[2]	Treatment[3]							
	1.18% dLys + 2890 kcal/kg AME	1.18% dLys + 2980 kcal/kg AME	1.18% dLys + 3070 kcal/kg AME	1.18% dLys + 3160 kcal/kg AME	1.28% dLys + 2890 kcal/kg AME	1.28% dLys + 2980 kcal/kg AME	1.28% dLys + 3070 kcal/kg AME	1.28% dLys + 3160 kcal/kg AME
	Avg[4]	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Lysine	1.36	1.38	1.37	1.34	1.52	1.43	1.45	1.44
Methionine	0.56	0.62	0.68	0.62	0.65	0.67	0.63	0.70
Cysteine	0.36	0.38	0.38	0.37	0.39	0.36	0.37	0.37
Methionine + Cysteine	0.92	1.00	1.05	0.98	1.04	1.03	0.99	1.06
Tryptophan	0.31	0.31	0.29	0.29	0.32	0.30	0.31	0.30
Threonine	0.89	0.90	0.90	0.90	0.98	0.92	0.93	0.95
Isoleucine	1.04	1.04	1.03	0.99	1.10	1.05	1.04	1.03
Valine	1.13	1.13	1.11	1.08	1.19	1.14	1.13	1.12
Arginine	1.46	1.49	1.47	1.46	1.59	1.48	1.50	1.50
Taurine	0.17	0.17	0.17	0.16	0.17	0.17	0.17	0.16
Aspartic acid	2.25	2.27	2.25	2.21	2.42	2.27	2.28	2.28
Serine	0.92	0.91	0.93	0.94	0.96	0.89	0.92	0.96
Glutamic acid	4.02	4.00	3.92	3.82	4.21	3.98	3.98	3.95
Proline	1.28	1.26	1.24	1.20	1.31	1.25	1.25	1.22
Glycine	0.93	0.93	0.92	0.91	1.00	0.94	0.94	0.94
Alanine	1.13	1.12	1.10	1.07	1.17	1.10	1.11	1.09
Leucine	1.92	1.92	1.88	1.83	1.98	1.89	1.89	1.87
Tyrosine	0.72	0.73	0.72	0.73	0.77	0.72	0.74	0.74
Phenylalanine	1.13	1.14	1.12	1.10	1.20	1.13	1.13	1.13
Histidine	0.60	0.60	0.59	0.58	0.63	0.59	0.60	0.59
Gross energy (kcal/kg)	3956.99	4042.00	4105.59	4167.96	4008.71	4068.20	4147.36	4204.01
Crude protein	23.01	23.25	22.28	22.15	23.65	22.80	23.24	22.72

[1]Feed samples were analyzed in duplicate at Missouri University labs. Columbia, MO. Official Methods of Analysis of AOAC International: Amino acid (AA) by Performic acid (Cysteine and Methionine); AA by Sodium hydroxide (Tryptophan); AA by Hydrochloric acid (all other AA).
[2]W/W%
[3]Dietary treatments were formulated to: Trt 1 = 1.18% digestible Lys (dLys) + 2890 kcal/kg AME; Trt 2 = 1.18% dLys + 2980 kcal/kg AME; Trt 3 = 1.18% dLys + 3070 kcal/kg AME; Trt 4 = 1.18% dLys + 3160 kcal/kg AME; Trt 5 = 1.28% dLys + 2890 kcal/kg AME; Trt 6 = 1.28% dLys + 2980 kcal/kg AME; Trt 7 = 1.28% dLys + 3070 kcal/kg AME; Trt 8 = 1.28% dLys + 3160 kcal/kg AME
[4]Average of two analyzed samples/treatment

Table 5.3. Diet formulations for grower (d 14-28) and finisher (d 28-41) phases[1]

Ingredient Name	Common diet	
	Grower (d 14-28)	Finisher (d 28-41)
Corn	65.30	66.80
Soybean meal (48% CP)	29.10	26.90
Soybean oil	2.59	3.54
Defluorinated phosphate	1.21	1.00
Calcium carbonate	0.56	0.54
Salt, NaCl	0.20	0.23
L-Lysine HCl	0.13	0.08
L-Threonine	0.08	0.06
DL-Methionine	0.24	0.21
Phytase[2]	0.01	0.01
Sodium S-Carb	0.15	0.15
Vitamin-trace mineral	0.25	0.25
Selenium premix 0.06%	0.02	0.02
Choline Cl-70%	0.07	0.08
Antibiotic[3]	0.05	0.05
Coccidiostat[4]	0.03	0.03
Nutrient Name	**Calculated Nutrients (%)[5]**	
AME (kcal/kg)	3086.47	3170.25
Crude protein (%)	19.50	18.50
Crude fat (%)	4.80	5.70
Linoleic acid (%)	1.35	1.37
Calcium (%)	0.84	0.76
Total phosphorus (%)	0.58	0.53
Available phosphorus (%)	0.42	0.38
Sodium (%)	0.20	0.20
Potassium (%)	0.77	0.73
Chloride (%)	0.20	0.21
Na+K-Cl (mEq/kg)	228.00	216.00
Digestible lysine (%)	1.05	0.95
Digestible methionine (%)	0.52	0.48
Digestible methionine +Digestible cysteine (%)	0.80	0.74
Digestible tryptophan (%)	0.20	0.19
Digestible threonine (%)	0.69	0.65
Digestible isoleucine (%)	0.74	0.70
Digestible valine (%)	0.82	0.78
Digestible arginine (%)	1.17	1.11
Choline (mg/kg)	1543	1543

[1]All birds were fed with a common diet on grower (d 14-28) and finisher (d 28-41) phases
[2]Quantum Blue (*E.Coli* phytase). AB Vista, Plantation, FL.
[3]BMD-50 (Bacitracin methylene disalicylate). Zoetis, Parsippany, NJ.
[4]Nicarb 25% (Nicarbazin). Phibro, Teaneck, NJ.
[5]Values are calculated based on the analyzed nutrient composition of corn and soybean meal at Missouri University labs. Columbia, MO

Table 5.4. Analyzed nutrients for grower (d 14-28) and finisher (d 28-41) feed samples[1]

Nutrient Name[2]	Common diet	
	Grower (d 14-28)	Finisher (d 28-41)
	Avg[3]	Avg
Lysine	1.16	1.07
Methionine	0.52	0.49
Cysteine	0.32	0.31
Tryptophan	0.24	0.23
Threonine	0.79	0.74
Isoleucine	0.85	0.87
Valine	0.91	0.87
Arginine	1.18	1.14
Taurine	0.20	0.20
Aspartic acid	1.83	1.74
Serine	0.79	0.78
Glutamic acid	3.32	3.23
Proline	1.08	1.09
Glycine	0.77	0.75
Alanine	0.95	0.95
Leucine	1.64	1.61
Tyrosine	0.61	0.60
Phenylalanine	0.96	0.92
Hydroxylysine	0.04	0.05
Ornithine	0.01	0.01
Histidine	0.49	0.47
Hydroxyproline	0.03	0.02
Gross energy (kcal/kg)	4079.43	4121.70
Crude protein	19.31	18.60

[1]Feed samples were analyzed in duplicate at Missouri University labs. Columbia, MO. Grower diet was formulated to 1.05% digestible lysine (dLys) + 3086.47 kcal/kg energy (AME), and finisher diet was formulated to 0.95% dLys + 3170.25 kcal/kg AME
[2]W/W%
[3]Average of two analyzed samples/diet

Table 5. 5. The effect of varying digestible lysine (dLys) and apparent metabolizable energy (AME) levels on d 0-14 Cobb MV × Cobb 500 male performance[1]

Starter dLys level (%)	Starter AME level (kcal/kg)	d 14 Avg[2] BW[3] (kg)	d 0-14 BWG[4] (kg)	d 0-14 Avg FI[5]/bird (kg)	d 0-14 FCR[6]	d 0-14 uFCR[7]	d 0-14 Percent Mortality[8]
1.18	**2890**	0.469	0.425	0.533	1.261	1.266	1.191
	2980	0.477	0.432	0.532	1.244	1.256	1.786
	3070	0.482	0.436	0.529	1.208	1.214	1.786
	3160	0.482	0.435	0.523	1.202	1.206	1.191
1.28	**2890**	0.477	0.433	0.534	1.232	1.237	2.381
	2980	0.495	0.449	0.535	1.193	1.204	2.976
	3070	0.489	0.445	0.523	1.175	1.177	2.381
	3160	0.488	0.443	0.522	1.161	1.168	1.786
Marginal means – Starter dLys level							
1.18%		0.478	0.433	0.529	1.226[a]	1.233[a]	1.488
1.28%		0.487	0.442	0.528	1.192[b]	1.197[b]	2.381
SEM[9]		0.0025	0.0025	0.0028	0.0033	0.0037	0.4967
Marginal means – Starter AME level							
2890 kcal/kg		0.473	0.429	0.533	1.245[a]	1.251[a]	1.786
2980 kcal/kg		0.488	0.442	0.533	1.219[b]	1.228[b]	2.381
3070 kcal/kg		0.485	0.440	0.526	1.193[c]	1.197[c]	2.083
3160 kcal/kg		0.484	0.438	0.522	1.182[c]	1.187[c]	1.488
SEM		0.0035	0.0035	0.0040	0.0047	0.0052	0.7025
P-values							
dLys[10]		0.2700	0.2700	0.6015	<0.0001	<0.0001	0.3637
AME[11]		0.1139	0.1139	0.2279	<0.0001	<0.0001	0.6250
dLys × AME[12]		0.9336	0.9336	0.8792	0.5509	0.8101	0.9952

[1]Dietary treatments were formulated to: Trt 1 = 1.18% dLys + 2890 kcal/kg AME; Trt 2 = 1.18% dLys + 2980 kcal/kg AME; Trt 3 = 1.18% dLys + 3070 kcal/kg AME; Trt 4 = 1.18% dLys + 3160 kcal/kg AME; Trt 5 = 1.28% dLys + 2890 kcal/kg AME; Trt 6 = 1.28% dLys + 2980 kcal/kg AME; Trt 7 = 1.28% dLys + 3070 kcal/kg AME; Trt 8 = 1.28% dLys + 3160 kcal/kg AME
[2]Average
[3]Body Weight (kg)
[4]Body Weight Gain (kg)
[5]Feed Intake/bird (kg)
[6]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[7]Feed Conversion Ratio (Feed:Gain) was not adjusted with mortality weight
[8]Percent Mortality is based on a beginning pen number of 14 birds
[9]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[10]P-values for dLys main effect; alpha set at P≤0.05
[11]P-values for AME main effect; alpha set at P≤0.05
[12]P-values for dLys × AME interaction; alpha set at P≤0.05
[a-c]Values within columns with different superscripts differ significantly (P<0.05)

Table 5.6. The carryover effect of feeding starter (d 0-14) diets varying in digestible lysine (dLys) and apparent metabolizable energy (AME) levels on d 0-28 Cobb MV × Cobb 500 male broiler performance[1]

Starter dLys level (%)	Starter AME level (kcal/kg)	d 28 Avg[2] BW[3] (kg)	d 0-28 BWG[4] (kg)	d 0-28 Avg FI[5]/bird (kg)	d 0-28 FCR[6]	d 0-28 uFCR[7]	d 0-28 Percent Mortality[8]
1.18	**2890**	1.576	1.532	2.170	1.415	1.437[a]	1.191
	2980	1.603	1.558	2.169	1.398	1.401[b]	1.786
	3070	1.598	1.552	2.183	1.402	1.390[b]	2.381
	3160	1.625	1.579	2.199	1.392	1.355[c]	1.786
1.28	**2890**	1.605	1.561	2.177	1.405	1.427[a]	2.976
	2980	1.610	1.564	2.194	1.400	1.387[b]	3.571
	3070	1.616	1.572	2.172	1.383	1.434[a]	2.976
	3160	1.602	1.557	2.171	1.386	1.397[b]	2.976
Marginal means – Starter dLys level							
1.18%		1.600	1.555	2.179	1.402	1.404	1.786
1.28%		1.604	1.560	2.174	1.394	1.399	3.125
SEM[9]		0.0078	0.0078	0.0101	0.0027	0.0028	0.5391
Marginal means – Starter AME level							
2890 kcal/kg		1.592	1.548	2.175	1.410[a]	1.411	2.083
2980 kcal/kg		1.604	1.558	2.177	1.399[ab]	1.402	2.679
3070 kcal/kg		1.602	1.558	2.171	1.393[b]	1.401	2.679
3160 kcal/kg		1.610	1.565	2.183	1.389[b]	1.393	2.381
SEM		0.0110	0.0110	0.0142	0.0038	0.0040	0.7624
P-values							
Starter dLys[10]		0.8462	0.8462	0.7806	0.2173	0.0376	0.1156
Starter AME[11]		0.7502	0.7502	0.9988	<0.0001	0.0002	0.8398
Starter dLys × AME[12]		0.4037	0.4037	0.9421	0.1047	0.0275	0.9391

[1]Common diets were fed to all birds from d 14-41; therefore d 0-28 includes a carryover effect of feeding diets varying in dLys and AME levels from d 0-14. Dietary treatments were formulated to: Trt 1 = 1.18% dLys + 2890 kcal/kg AME; Trt 2 = 1.18% dLys + 2980 kcal/kg AME; Trt 3 = 1.18% dLys + 3070 kcal/kg AME; Trt 4 = 1.18% dLys + 3160 kcal/kg AME; Trt 5 = 1.28% dLys + 2890 kcal/kg AME; Trt 6 = 1.28% dLys + 2980 kcal/kg AME; Trt 7 = 1.28% dLys + 3070 kcal/kg AME; Trt 8 = 1.28% dLys + 3160 kcal/kg AME
[2]Average
[3]Body Weight (kg)
[4]Body Weight Gain (kg)
[5]Feed Intake/bird (kg)
[6]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[7]Feed Conversion Ratio (Feed:Gain) was not adjusted with mortality weight
[8]Percent Mortality is based on a beginning pen number of 14 birds
[9]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[10]P-values for dLys main effect; alpha set at P≤0.05
[11]P-values for AME main effect; alpha set at P≤0.05
[12]P-values for dLys × AME interaction; alpha set at P≤0.05
[a-c]Values within columns with different superscripts differ significantly (P<0.05)

Table 5.7. The carryover effect of feeding grower (d 0-14) diets varying in digestible lysine (dLys) and apparent metabolizable energy (AME) levels on d 0-41 Cobb MV × Cobb 500 male broiler performance[1]

Starter dLys level (%)	Starter AME level (kcal/kg)	d 41 Avg[2] BW[3] (kg)	d 0-41 BWG[4] (kg)	d 0-41 Avg FI[5]/bird (kg)	d 0-41 FCR[6]	d 0-41 uFCR[7]	d 0-41 Percent Mortality[8]
1.18	**2890**	2.577	2.533	4.114	1.618	1.628	1.786
	2980	2.597	2.552	4.259	1.614	1.672	6.548
	3070	2.586	2.540	4.186	1.621	1.653	4.762
	3160	2.691	2.645	4.274	1.600	1.626	4.167
1.28	**2890**	2.617	2.572	4.229	1.625	1.651	4.761
	2980	2.602	2.556	4.201	1.627	1.656	5.952
	3070	2.557	2.513	4.149	1.599	1.614	4.762
	3160	2.571	2.526	4.070	1.620	1.640	4.167
Marginal means – Starter dLys level							
1.18%		2.613	2.567	4.208	1.613	1.642	4.315
1.28%		2.578	2.533	4.156	1.617	1.640	4.911
SEM[9]		0.0263	0.0263	0.0327	0.0063	0.0087	0.7519
Marginal means – Starter AME level							
2890 kcal/kg		2.597	2.552	4.171	1.622	1.639	3.274
2980 kcal/kg		2.599	2.554	4.230	1.620	1.661	6.250
3070 kcal/kg		2.552	2.508	4.153	1.607	1.632	4.762
3160 kcal/kg		2.631	2.585	4.176	1.610	1.633	4.167
SEM		0.0372	0.0372	0.0462	0.0089	0.0123	1.0634
P-values							
Starter dLys[10]		0.8841	0.8841	0.9658	0.6715	0.6790	0.7666
Starter AME[11]		0.9291	0.9291	0.7606	0.5723	0.2508	0.2950
Starter dLys × AME[12]		0.6583	0.6583	0.1288	0.5014	0.2598	0.5392

[1]Common diets were fed to all birds from d 14-41; therefore d 0-41 includes a carryover effect of feeding diets varying in dLys and AME levels from d 0-14. Dietary treatments were formulated to: Trt 1 = 1.18% dLys + 2890 kcal/kg AME; Trt 2 = 1.18% dLys + 2980 kcal/kg AME; Trt 3 = 1.18% dLys + 3070 kcal/kg AME; Trt 4 = 1.18% dLys + 3160 kcal/kg AME; Trt 5 = 1.28% dLys + 2890 kcal/kg AME; Trt 6 = 1.28% dLys + 2980 kcal/kg AME; Trt 7 = 1.28% dLys + 3070 kcal/kg AME; Trt 8 = 1.28% dLys + 3160 kcal/kg AME
[2]Average
[3]Body Weight (kg)
[4]Body Weight Gain (kg)
[5]Feed Intake/bird (kg)
[6]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[7]Feed Conversion Ratio (Feed:Gain) was not adjusted with mortality weight
[8]Percent Mortality is based on a beginning pen number of 14 birds
[9]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[10]P-values for dLys main effect; alpha set at $P \leq 0.05$
[11]P-values for AME main effect; alpha set at $P \leq 0.05$
[12]P-values for dLys × AME interaction; alpha set at $P \leq 0.05$
[a-c]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 5.8. The effect of varying digestible lysine (dLys) and apparent metabolizable energy (AME) levels from d 0-14 on d 42 processing characteristics reported as average yield relative to d 41 live weight[1]

Starter dLys level (%)	Starter AME level (kcal/kg)	d 41 Avg[2] BW[3] (kg)	Yield relative to d 41 live weight (%)[4]						
			Carcass	Breast[5]	Tender[6]	Drumstick	Thigh	Wing	Fat Pad
1.18	**2890**	2.552	72.382	18.540	3.963	10.225	12.882	8.014	1.238
	2980	2.593	72.781	18.740	3.890	10.076	12.824	8.104	1.253
	3070	2.576	72.595	18.741	3.833	9.926	12.761	7.978	1.173
	3160	2.682	72.138	18.850	3.856	10.264	12.799	7.981	1.205
1.28	**2890**	2.632	72.388	18.903	3.746	9.970	12.785	8.057	1.144
	2980	2.600	72.765	18.825	3.870	10.175	12.949	8.120	1.228
	3070	2.559	72.472	18.692	3.899	9.876	12.561	8.050	1.298
	3160	2.568	72.455	18.457	3.892	10.094	12.769	8.193	1.133
Marginal means – Starter dLys level									
1.18%		2.600	72.474	18.718	3.886	10.123	12.836	8.019	1.217
1.28%		2.582	72.535	18.699	3.845	10.047	12.801	8.108	1.200
SEM[7]		0.0254	0.1213	0.1342	0.0310	0.0553	0.1042	0.0451	0.0228
Marginal means – Starter AME level									
2890 kcal/kg		2.592	72.385	18.722	3.855	10.098	12.834	8.035	1.191
2980 kcal/kg		2.596	72.773	18.783	3.880	10.125	12.930	8.112	1.240
3070 kcal/kg		2.548	72.567	18.675	3.857	9.928	12.724	8.013	1.238
3160 kcal/kg		2.625	72.297	18.653	3.872	10.179	12.784	8.087	1.169
SEM		0.0360	0.1717	0.1899	0.0438	0.0782	0.1474	0.0638	0.0322
P-values									
Starter dLys[8]		0.7686	0.7901	0.9943	0.4425	0.2355	0.7338	0.1851	0.6111
Starter AME[9]		0.7370	0.2203	0.9711	0.9786	0.0859	0.7460	0.6886	0.3298
Starter dLys × AME[10]		0.2949	0.8248	0.5562	0.1051	0.4056	0.8936	0.6989	0.0927

[1]Common diets were fed to all birds from d 14-41; therefore processing characteristics at d 42 (reported as average yield relative to d 41 live weight) are a carryover effect of feeding diets varying in dLys and AME levels from d 0-14. Dietary treatments were formulated to: Trt 1 = 1.18% dLys + 2890 kcal/kg AME; Trt 2 = 1.18% dLys + 2980 kcal/kg AME; Trt 3 = 1.18% dLys + 3070 kcal/kg AME; Trt 4 = 1.18% dLys + 3160 kcal/kg AME; Trt 5 = 1.28% dLys + 2890 kcal/kg AME; Trt 6 = 1.28% dLys + 2980 kcal/kg AME; Trt 7 = 1.28% dLys + 3070 kcal/kg AME; Trt 8 = 1.28% dLys + 3160 kcal/kg AME
[2]Average
[3]Body Weight (kg)
[4]Yield relative to d 41 live weight (%)
[5]Breast refers to the pectoralis major
[6]Tender refers to the pectoralis minor
[7]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[8]P-values for dLys main effect; alpha set at $P \leq 0.05$
[9]P-values for AME main effect; alpha set at $P \leq 0.05$
[10]P-values for dLys × AME interaction; alpha set at $P \leq 0.05$
[a-c]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 5.9. The effect of varying digestible lysine (dLys) and apparent metabolizable energy (AME) levels from d 0-14 on d 42 processing characteristics reported as average yield relative to d 42 carcass weight[1]

Starter dLys level (%)	Starter AME level (kcal/kg)	Carcass wt[2] (kg)	Yield relative to d 42 carcass weight[3] (%)					
			Breast[4]	Tender[5]	Drumstick	Thigh	Wing	Fat Pad
1.18	**2890**	1.851	25.631	5.482	14.088	17.752	11.082	1.681
	2980	1.883	25.678	5.347	13.808	17.663	11.106	1.724
	3070	1.868	25.811	5.285	13.673	17.571	10.992	1.616
	3160	1.933	26.128	5.348	14.192	17.735	11.062	1.675
1.28	**2890**	1.906	26.103	5.171	13.778	17.663	11.134	1.581
	2980	1.892	25.871	5.317	13.995	17.796	11.161	1.689
	3070	1.863	25.608	5.370	13.638	17.122	11.118	1.814
	3160	1.861	25.474	5.377	13.949	17.616	11.306	1.564
Marginal means – Starter dLys level								
1.18%		1.884	25.812	5.366	13.949	17.680	11.061	1.673
1.28%		1.879	25.758	5.301	13.864	17.567	11.180	1.663
SEM[6]		0.0181	0.1733	0.0419	0.0749	0.1388	0.0602	0.0317
Marginal means – Starter AME level								
2890 kcal/kg		1.878	25.867	5.326	13.933	17.707	11.108	1.626
2980 kcal/kg		1.888	25.774	5.332	13.918	17.729	11.134	1.706
3070 kcal/kg		1.862	25.695	5.320	13.689	17.374	11.049	1.719
3160 kcal/kg		1.897	25.801	5.359	14.070	17.675	11.184	1.619
SEM		0.0256	0.2451	0.0592	0.1060	0.1963	0.0851	0.0448
P-values								
Starter dLys[7]		0.8932	0.8450	0.3392	0.3503	0.5067	0.1655	0.7831
Starter AME[8]		0.8453	0.9759	0.9697	0.0609	0.4864	0.7566	0.3051
Starter dLys × AME[9]		0.3709	0.3940	0.0945	0.3446	0.7777	0.8386	0.0636

[1]Common diets were fed to all birds from d 14-41; therefore, processing characteristics at d 42 (reported as average yield relative to carcass weight) are a carryover effect of feeding diets varying in dLys and AME levels from d 0-14. Dietary treatments were formulated to: Trt 1 = 1.18% dLys + 2890 kcal/kg AME; Trt 2 = 1.18% dLys + 2980 kcal/kg AME; Trt 3 = 1.18% dLys + 3070 kcal/kg AME; Trt 4 = 1.18% dLys + 3160 kcal/kg AME; Trt 5 = 1.28% dLys + 2890 kcal/kg AME; Trt 6 = 1.28% dLys + 2980 kcal/kg AME; Trt 7 = 1.28% dLys + 3070 kcal/kg AME; Trt 8 = 1.28% dLys + 3160 kcal/kg AME
[2]Carcass weight (kg)
[3]Yield relative to carcass weight (%)
[4]Breast refers to the pectoralis major
[5]Tender refers to the pectoralis minor
[6]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[7]P-values for dLys main effect; alpha set at $P \leq 0.05$
[8]P-values for AME main effect; alpha set at $P \leq 0.05$
[9]P-values for dLys × AME interaction; alpha set at $P \leq 0.05$
[a-c]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 5.10. The effect of varying digestible lysine (dLys) and apparent metabolizable energy (AME) levels from d 0-14 on d 42 processing characteristics reported as average weight[1]

Starter dLys level (%)	Starter AME level (kcal/kg)	Avg[2] weight (kg)					
		Breast[3]	Tender[4]	Drumstick	Thigh	Wing	Fat Pad
1.18	**2890**	0.474	0.101	0.260	0.328	0.204	0.032
	2980	0.488	0.101	0.259	0.332	0.210	0.033
	3070	0.484	0.099	0.255	0.327	0.205	0.031
	3160	0.506	0.104	0.273	0.342	0.214	0.032
1.28	**2890**	0.500	0.098	0.262	0.336	0.212	0.030
	2980	0.492	0.101	0.264	0.335	0.211	0.032
	3070	0.488	0.101	0.257	0.325	0.209	0.033
	3160	0.475	0.100	0.259	0.327	0.210	0.029
Marginal means – Starter dLys level							
1.18%		0.488	0.101	0.262	0.332	0.208	0.032
1.28%		0.488	0.100	0.260	0.331	0.210	0.031
SEM[5]		0.0063	0.0013	0.0023	0.0038	0.0019	0.0007
Marginal means – Starter AME level							
2890 kcal/kg		0.487	0.100	0.261	0.332	0.208	0.031
2980 kcal/kg		0.490	0.101	0.262	0.333	0.210	0.323
3070 kcal/kg		0.486	0.100	0.256	0.326	0.207	0.032
3160 kcal/kg		0.491	0.101	0.266	0.335	0.212	0.031
SEM		0.0089	0.0018	0.0033	0.0054	0.0027	0.0010
P-values							
Starter dLys[6]		0.9643	0.5974	0.5588	0.7760	0.4229	0.3271
Starter AME[7]		0.9791	0.8902	0.2275	0.6914	0.6483	0.6260
Starter dLys × AME[8]		0.1654	0.6345	0.1597	0.4487	0.4739	0.3346

[1]Common diets were fed to all birds from d 14-41; therefore, processing characteristics at d 42 (reported as average weight) are a carryover effect of feeding diets varying in dLys and AME levels from d 0-14. Dietary treatments were formulated to: Trt 1 = 1.18% dLys + 2890 kcal/kg AME; Trt 2 = 1.18% dLys + 2980 kcal/kg AME; Trt 3 = 1.18% dLys + 3070 kcal/kg AME; Trt 4 = 1.18% dLys + 3160 kcal/kg AME; Trt 5 = 1.28% dLys + 2890 kcal/kg AME; Trt 6 = 1.28% dLys + 2980 kcal/kg AME; Trt 7 = 1.28% dLys + 3070 kcal/kg AME; Trt 8 = 1.28% dLys + 3160 kcal/kg AME
[2]Average
[3]Breast refers to the pectoralis major
[4]Tender refers to the pectoralis minor
[5]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[6]P-values for dLys main effect; alpha set at $P \leq 0.05$
[7]P-values for AME main effect; alpha set at $P \leq 0.05$
[8]P-values for dLys × AME interaction; alpha set at $P \leq 0.05$
[a-c]Values within columns with different superscripts differ significantly ($P<0.05$)

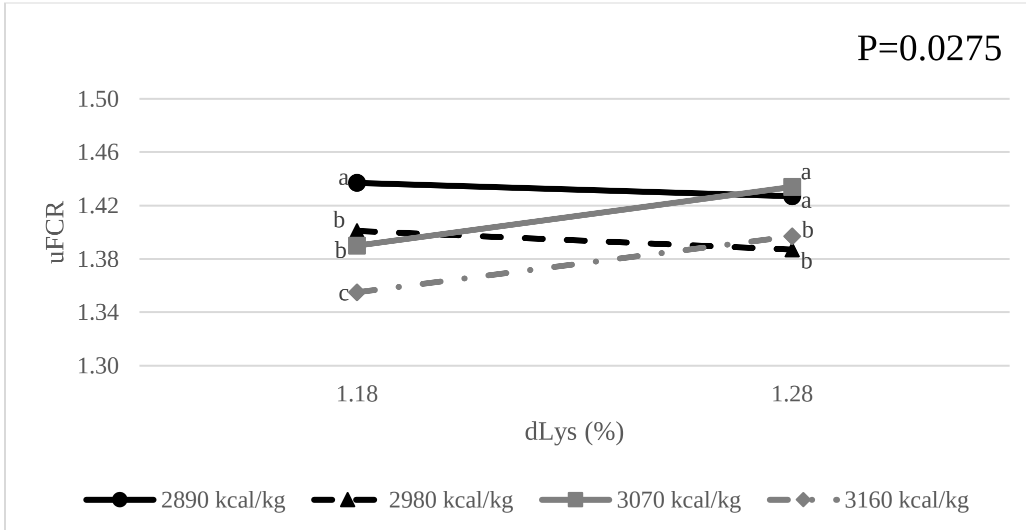

Figure 5.1. Digestible lysine (dLys) × Apparent metabolizable energy (AME) interaction for d 0-28 feed conversion ratio uncorrected for mortality (uFCR)[1]

[1]Common diets were fed to all birds from d 14-41; therefore d 0-28 includes a carryover effect of feeding diets varying in dLys and AME levels from d 0-14. Dietary treatments were formulated to: Trt 1 = 1.18% dLys + 2890 kcal/kg AME; Trt 2 = 1.18% dLys + 2980 kcal/kg AME; Trt 3 = 1.18% dLys + 3070 kcal/kg AME; Trt 4 = 1.18% dLys + 3160 kcal/kg AME; Trt 5 = 1.28% dLys + 2890 kcal/kg AME; Trt 6 = 1.28% dLys + 2980 kcal/kg AME; Trt 7 = 1.28% dLys + 3070 kcal/kg AME; Trt 8 = 1.28% dLys + 3160 kcal/kg AME
[a-c]Means within a column not sharing a common superscript differ ($P<0.05$)

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CHAPTER VI

IMPACT OF FEEDING VARYING GROWER DIGESTIBLE LYSINE AND ENERGY LEVELS TO FEMALE COBB MV × COBB 500 BROILERS ON 42-DAY GROWTH PERFORMANCE, PROCESSING, AND ECONOMIC RETURN

Summary

Previous research in our lab has revealed that feeding various levels of starter digestible lysine (dLys) and apparent metabolizable energy (AME) affects early bird performance of Cobb MV × Cobb 500 broilers. However, overall performance was not affected, likely due to treatment application occurring in the starter phase. Therefore, the objective of this study was to evaluate a 3 dLys (1.00, 1.08, and 1.18%) × 4 AME (2937, 3028, 3116, and 3206 kcal/kg) factorial arrangement of grower diet treatments (Gdiets) and their impact on performance and yield of 42-day old Cobb MV × Cobb 500 females. Common starter and finisher diets were fed. Based on d 14-28 and 14-35 data, significant dLys × AME interactions demonstrated that in general, feed conversion ratio (FCR) decreased as birds were fed Gdiets increasing in dLys for each AME. However, birds fed Gdiets at 1.08% dLys and 3028 kcal/kg AME demonstrated a slight plateau in FCR. Overall data exhibited improvements in body weight (BW) and BW gain (BWG) when feeding Gdiets of 1.08 or 1.18% dLys. Feeding Gdiets of 1.18% dLys or ≥3028 kcal/kg AME optimized d 14-41 FCR. Processing data demonstrated improved breast yield when feeding Gdiets formulated to ≥1.08% dLys or formulated to 2937 or 3028 kcal/kg AME.

At d 42, the most profitable Gdiet was 1.18% dLys + 3028 kcal/kg AME. To determine the best feeding regime for this new cross, future research should evaluate the effects of varying dLys and AME levels during the finisher phase on broiler performance.

Description of the Problem

To reduce costs and optimize performance, several feeding strategies have been studied. Among them, evaluating the effects of feeding different levels of amino acids (AA) and apparent metabolizable energy (AME) on broiler performance is important since the feed ingredients that provide AA and AME in the diets are the main contributors to the feed cost, which corresponds to 60-70% of total broiler production [1].

Previous literature reported that AA × AME interactions may greatly affect broiler performance [2]. A previous study conducted in our lab aimed to evaluate the effects of a 2 digestible lysine (dLys) × 4 AME factorial arrangement of treatments during the starter phase on the performance and yield of Cobb MV × Cobb 500 males at d 42. Improvements in performance at d 14 were observed when feeding starter diets formulated to 1.28% dLys or ≤3070 kcal/kg AME [3]. Additionally, a significant interaction between dLys and AME was observed for feed conversion ratio (FCR) corrected for mortality, where feeding 1.18% dLys + 3160 kcal/kg AME during the starter phase demonstrated the lowest FCR (uncorrected for mortality) at d 28 [3]. However, no significant interaction, nor significance for the main effects were observed at the end of rearing period. Hence, more research is needed to explore the interaction of dLys and AME on Cobb MV × Cobb 500 broiler performance in order to determine the best feeding strategy. Therefore, the objective of this study was to determine the response of Cobb MV × Cobb 500 female broilers fed varying dLys and AME levels during the grower phase on d 14-28 growth performance, as well as the carryover effect of these dietary treatments on 42-day growth performance, processing yield, and economic return.

Materials and Methods

Broiler Management

Day-old female chicks were provided from a commercial hatchery and equally distributed to 96 pens (0.074 m^2/bird, 15 females/pen) [4]. Each pen contained fresh shavings over used litter, a hanging feeder, and three nipple drinkers. The research facility was a solid-walled house with forced-air heating, cool cells, and cross-ventilation by negative air pressure. From d 0-14, chicks were fed a common diet. On d 14, all birds were weighed, and pen weights were equalized by block, keeping 13 females per pen (0.086 m^2/bird) that were provided with experimental diets until d 28. The procedure of equalizing pen weights was conducted to ensure that any significance was due to the different levels of dLys and AME fed in the grower phase (d 14-28). Common diets were also provided in the finisher (d 28-41) phase to look at carryover effects of feeding varying dLys × AME diets in the grower phase.

The temperature was 32.2°C at placement and slowly decreased until reaching 18.3°C at the end of the grow-out period [5]. The lighting program followed breeder recommendations, with 24 h of light during the first 7 d of age and 4 h of dark from d 7 to 42. Light intensity was 26.9 lux during the first 10 d and gradually decreased until reaching 2.7 lux on d 21 and remaining at this intensity until d 42 [5]. Additionally, temperature and light were monitored daily and bird mortality was recorded twice a day. Birds were provided with water and feed *ad libitum* throughout the study diet.

Experimental Diet Preparations

Diet Formulation

Twelve experimental diets were formulated to dLys levels of 1.00, 1.08, and 1.18% and AME levels of 2937, 3028, 3116, and 3206 kcal/kg, which were provided to birds from d 14-28 (Table 6.1). To make sure the available nutrient values of these experimental grower diets (Gdiets) and the two common basal diets (starter and finisher) were close to the target nutrients, corn and soybean meal were scanned using Near Infrared (NIR) Spectroscopy [6] and analyzed for nutrient content [7-9]. This was done prior to formulation to ensure diets were as close to nutrient targets as possible (Tables 6.1-6.4).

Batching

Basal diets were manufactured at the Poultry Research Unit, Mississippi State University, in which grower diets were individually batched. A premix for each diet was made for ingredients with inclusions under 0.5% (such as trace minerals, vitamins, and synthetic amino acids). The appropriate premixes and macro ingredients (e.g corn and soybean meal) were mixed for 5 minutes in a 0.907-tonne vertical screw mixer [10]. Afterwards, each diet had the appropriate soybean oil added and was mixed for an additional 10 minutes to create a homogenous mix.

Feed Manufacture

The pelleting process was performed at the Poultry Research Unit – U.S. Department of Agriculture in Starkville, MS; all diets were steam conditioned at 81°C with a 262 kPa incoming steam pressure for 10 seconds. Experimental diets for the grower phase were pelleted in order of increasing dLys and AME, with whole grain corn being flushed in the mixer between dLys levels to avoid cross contamination. Finished feed samples were collected and sent for laboratory analysis [7, 9]. The common starter was fed as crumbles from d 0-14, while grower experimental diets and the common finisher diet were fed as pellets from d 14-28 and 28-42, respectively.

Measured Variables

Live Performance

To calculate average body weight (BW), BW gain (BWG), average feed intake/bird (FI), and FCR corrected for mortality, pen feed intake and individual bird weights were collected at d 14, 28, 35, and 41. All experimental procedures and animal handling were conducted in accordance with the guidelines from the Mississippi State University Institutional Animal Care and Use Committee, which was based on the Guide for the Care and Use of Agricultural Animals Research and Teaching [11].

Processing Measurements

On d 41, three birds/pen within 100 g of average BW/pen were selected and tagged (total of 288 females). After fasting for approximately 10 h, these birds were processed and deboned at the Mississippi State University Poultry Processing Plant on the following day. All broilers were hung by their feet on an automated processing line and electronically stunned before exsanguination via neck cutting with a knife. Next, broilers were put under hot water (52-66°C) and had their feathers removed by a plucking machine with rubber fingers. Then, their feet were manually removed, and carcasses were rehung on another automated line, in which heads, necks, and viscera were mechanically removed. Each carcass had its abdominal fat pad removed and weighed. Afterwards, hot carcasses were pulled off of the processing line and weighed. All carcasses were chilled in an ice bath (≤4°C) for 3 h. After chilling, each carcass was deboned on a stationary line by 1 of 3 trained people. To obtain the processing yield relative to live BW and carcass weight, the following chicken parts were weighed: boneless skinless breast (pectoralis major), tender (pectoralis minor), thigh, drumstick, and wing.

Economic Analysis

To determine the diet cost, the production cost/bird, the potential gross chicken part value, and the potential profit for each dietary treatment, ingredient prices from Feedstuffs and USDA [12, 13] and chicken part values in the market [14] were used, and the following equations were utilized for calculation.

Potential gross chicken part values = Processing data (chicken parts wt in kg) * Chicken part value in the market (cents) (6.1)

Total potential gross chicken part value/bird (cents) = sum of all potential gross chicken part values/bird (6.2)

Total feed cost/bird (cents) = Average feed intake (kg) * Feed cost (cents/kg) (6.3)

Total feed cost/bird (dollars) = Total feed cost/bird (cents) / 100 (6.4)

Gross bird profit (cents) = Total potential gross profit/bird (cents) – Total feed cost/bird (cents) (6.5)

Gross bird profit (dollars; in kg) = Gross bird profit (cents) / 100 (6.6)

Statistical Analysis

A 3 × 4 factorial arrangement of treatments within a randomized complete block design (RCBD) was used in the current study (d 0-42). Each dietary treatment had 8 replicated floor pens with 13 females/pen, in which each floor pen was considered an experimental unit. The GLM procedure (two-way ANOVA) in SAS was utilized to analyze the measured variables [15]. Significance level was set at P≤0.05, and significant means were further explored with Fisher's least significant difference.

Results and Discussion

Feed Analysis

Based on the feed analysis results, in which all diets were analyzed for total AA, crude protein, and AME, it was observed that the analyzed values were similar to the target values (Tables 6.1-6.4).

Broiler Performance

As expected, no significant difference was observed for any measured variables during the starter phase (d 0-14; P>0.05): average BW = 0.423 kg, BWG = 0.383 kg, FI = 0.480 kg, FCR = 1.252, and percent mortality = 1.736%. In addition, no dLys × AME interaction was observed for BW, BWG, FI, and percent mortality throughout the study (P>0.05; Tables 6.5-6.7) was observed. No significant difference for the main effect of AME level for BW, BWG, and percent mortality during the rearing period (P>0.05; Tables 6.5-6.7). Additionally, no significance for the main effect of dLys level was established for d 14 and 35 BW (P>0.05; Tables 6.5 and 6.6). These results are inconsistent with a previous study using Cobb 700 straight-run broilers, where a significant AA density (AAD) × AME interaction for BW and FI at d 28, 35, 42, and 54 was observed [2]. Also, in disagreement with the current study, previous studies evaluating Ross × Ross 508 and Cobb 500 broilers reported improvements in d 14 BW when feeding higher AAD regimens [16-18].

Birds receiving diets formulated to 1.18% dLys had the highest d 28 BW (P<0.0001; Table 6.5). In addition, birds fed grower diets formulated to 1.08 and 1.118% dLys yielded improved d 41 BW as compared to birds fed grower diets formulated to 1.00% dLys (P=0.0293; Table 6.7). Also, performance data revealed that birds fed 1.18% dLys had the highest d 14-28 BWG during the grower phase (P<0.0001; Table 6.5). Additionally, there was an improvement in d 14-35 BWG when broilers were fed grower diets formulated to 1.18% dLys as compared to those fed grower diets of 1.00% dLys; birds fed 1.08% grower dLys had similar and intermediate BWG (P=0.0471; Table 6.6). Overall data showed that feeding 1.08 and 1.18% dLys during the grower phase improved d 14-41 BWG (P=0.0287; Table 6.7). In contrast with these results, a previous study using Cobb 700 broilers observed significant AAD × AME interactions for BW at d 28, 35, 42, and 54; where birds fed high AAD diet (at low AME level) decreased BW, however, BW was similar among birds receiving high AAD diets at high AME level [2]. In addition, no response was previously reported for d 35 BW when feeding a higher dietary AAD during the grower and finisher phases [19].

Significant differences for the main effect of dLys were established for d 14-28 and 14-35 FI (P<0.0001 and P=0.0421, respectively; Tables 6.5 and 6.6). Birds fed grower diets formulated to 1.18% dLys had a lower d 14-28 FI as compared to birds fed grower diets formulated to 1.00 and 1.08% dLys. Birds receiving grower diets of 1.18% dLys had a lower d 14-35 FI as compared to those fed grower diets formulated to 1.00% dLys, with birds fed 1.08% grower dLys having a similar and intermediate FI. In agreement with the current study, a decrease in d 28 and 35 FI of Cobb × Cobb 700 straight-run broilers when feeding a higher dietary AAD through-out the experimental period (d 0-56) has been previously reported [19]. These results agree with previous literature, where higher levels of dietary energy or nutrient density may have inhibited feed consumption, while diets formulated to low nutrient density may stimulate FI to compensate for the reduction in nutrient density [19-20].

In addition, significant differences for the main effect of AME were found throughout the experimental period. A stepwise decrease in d 14-28 FI was observed when increasing dietary AME levels during the grower phase (P<0.0001; Table 6.5). Results for d 14-35 FI showed that birds fed grower diets formulated to 3206 kcal/kg AME had the lowest FI, with birds receiving grower diets formulated to 3116 kcal/kg AME had a similar and intermediate FI (P<0.0001; Table 6.6). Overall data (d 14-41) demonstrated that feeding grower diets formulated to 3116 and 3206 kcal/kg AME decreased FI, with birds fed grower diets of 3028 kcal/kg AME having a similar and intermediate FI (P=0.0238; Table 6.7). As previously mentioned, this could be due to the ability of the bird to adjust its feed intake based on the diet nutrient density. For example, birds will consume less feed when provided with a higher density diet and they will have to consume more feed to obtain the same amount of nutrients if a lower density diet is provided to them [19-20].

Results demonstrated that there was a significant dLys × AME interaction for d 14-28 and 14-35 FCR (P=0.0016 and P=0.0427, respectively; Tables 6.5 and 6.6; Figures 6.1 and 6.2); in which FCR decreased as dLys increased for each AME level, with a slight plateau when increasing dLys from 1.00 to 1.08% for grower diets formulated to 3028 kcal/kg AME. However, by the end of the study, interactions for FCR that were previously obtained were lost (P>0.05; Table 6.7). Significant differences for the main effect of dLys for d 14-41 FCR were observed, in which there was a stepwise decrease in FCR when increasing dLys during the grower phase ($P<0.0001$; Table 6.7). In partial agreement with these results, previous research did not find significant dLys × AME interactions for FCR throughout the rearing period. However, they observed an improvement in d 28 FCR when birds received diets with higher AAD during the grower phase [2, 19]. Additionally, feeding grower diets formulated to ≥3028 kcal/kg AME decreased d 14-41 FCR ($P<0.0001$; Table 6.7). This result is consistent with previous literature, whereas a decrease in FCR was reported when feeding a higher ME level [20].

Processing

In general, processing data demonstrated no significant dLys × AME interactions for any measured variable. Additionally, no significant difference was established for the main effect of dLys level for carcass, tender, thigh and wing yields (relative to d 41 live weight); tender, thigh, and abdominal fat pad yields (relative to d 42 carcass weight); as well as tender, drumstick, thigh, and wing weights ($P>0.05$; Tables 6.8-6.10). Also, no significant difference for the main effect of AME was observed for carcass, tender, drumstick, thigh, wing, and abdominal fat pad yields (relative to d 41 live weight); carcass, tender, drumstick, thigh, wing, and abdominal fat pad yields (relative to d 42 carcass weight); and any processing weights ($P>0.05$; Tables 6.8-6.10). In disagreement, a previous study utilizing Cobb 700 broilers reported a significant AAD × AME interaction at d 55, where birds provided high AAD and low AME diets had the lowest carcass, breast wing, front half, and back half weights as compared to those fed the other diets [2]. Additionally, they found an increase in fat pad yield (relative to BW), a decrease in wing yield (relative to BW), as well as an increase in weights of drumstick, thigh, and fat pad when feeding higher AME diets [2]. An increase in fat deposition when birds were fed increased dietary energy level was observed. This was likely due to the dietary energy level associated to the activity of enzymes that produce fatty acids from acetyl-CoA in the chicken liver (hepatic *de novo* lipogenenis) [21]. Among these enzymes, the activity of fatty acid synthase (FAS) is important for hepatic lipogenesis, as it controls the ability of birds to produce fatty acid deposits in the body [22].

It was observed that feeding 1.18% dLys during the grower phase improved carcass weight as compared to 1.00% grower dLys, with birds fed 1.08% grower dLys having a similar and intermediate carcass weight (P=0.0137; Table 6.9). Results also showed an improvement in breast yield (relative to d 41 live weight and relative to d 42 carcass weight) when birds were fed 1.08 and 1.18% dLys from d 14-28, as compared to those fed grower diets formulated to 1.00% dLys (P=0.0002 and P<0.0001, respectively; Tables 6.8 and 6.9). There was a stepwise increase in d 42 breast weight when increasing dLys during the grower phase (P<0.0001; Table 6.10). Broilers fed grower diets formulated to 2937 and 3028 kcal/kg AME had greater breast yield (relative to d 41 live weight and relative to d 42 carcass weight) than those fed diets formulated to 3206 kcal/kg grower AME, with broilers fed 3116 kcal/kg grower AME having a similar and intermediate breast yield (P=0.0417 and P=0.0296, respectively; Tables 6. 8 and 6. 9).

Birds fed grower diets formulated to 1.00% dLys had the highest drumstick yield (relative to d 41 live weight and relative to d 42 carcass weight; P=0.0023 and P=0.0062, respectively; Tables 6.8 and 6.9). Birds receiving 1.18% dLys during the grower phase had the lowest abdominal fat pad yield (relative to d 41 live weight and relative to d 42 carcass weight; P=0.0038 and P=0.0027, respectively; Tables 6.8 and 6.9). In addition, feeding grower diets formulated to 1.18% dLys provided a lower abdominal fat pad weight as compared to 1.08% grower dLys, with birds fed 1.00% dLys having a similar and intermediate abdominal fat pad weight (P=0.0462; Table 6.10). These results are in partial agreement with a previous study, which reported a decrease in fat pad yield (relative to BW), as well as fat pad weight when feeding a higher AAD level [2]. This is likely because some AA can regulate lipid metabolism and fat deposition in the bird [23]. The addition of lysine improves the production of lean meat [23].

Economic Analysis

Based on economic return that was calculated only during a specific period of time (January of 2019) [12-14], the lowest potential cost saving/gross profit per bird was observed when feeding 1.00% dLys + 3206 kcal/kg AME during the grower phase, while the highest potential cost saving/gross profit per bird was found birds were fed grower diets at 1.18% dLys + 3028 kcal/kg AME, with an increase of $0.19 in potential cost saving/gross profit per bird (Table 6.11). Also, feeding grower diets of 1.18% dLys + 3028 kcal/kg AME demonstrated an increase of $0.05 in potential cost saving/gross profit per bird in comparison to the grower diets (1.08% dLys + 3028 or 3116 kcal/kg AME) that were closer to the breeder recommendations [24]. However, it is important to continuously reevaluate the relationship between feed costs and processing yield due to the constant change in the costs of feed ingredients and chicken part values [19].

Summary and Future Direction

This study draws attention to the importance of evaluating the response of Cobb MV × Cobb 500 broilers to different levels of dLys and AME during the grower phase. Based on this current study, a significant dLys × AME interaction was established for d

14-28 and 14-35 FCR, where there was a decrease in FCR as Gdiets increasing in dLys and AME were fed. However, broilers fed Gdiets at 1.08% dLys + 3028 kcal/kg AME had a slight plateau in FCR. Data (d 14-41) demonstrated that feeding Gdiets at 1.08 or 1.18% dLys improved BW and BWG. Also, feeding 1.18% dLys or ≥3028 kcal/kg AME during the grower phase optimized d 14-41 FCR. Based on the processing data, an improvement in breast yield was observed when birds received Gdiets formulated to ≥1.08% dLys, as well as 2937 or 3028 kcal/kg AME. Feeding 1.18% dLys + 3028 kcal/kg AME during the grower phase was the most profitable diet at the end of the study. In order to fully capitalize on the economic potential of this new cross, future research should evaluate the effects of varying dLys and AME during the finisher phase.

Conclusion and Applications

1. A significant dLys × AME interaction was observed for d 14-28 and 14-35 FCR. In general, there was a decrease in FCR of Cobb MV × Cobb 500 females when increasing dLys for each AME level, though a slight plateau was found as dLys increased from 1.00 to 1.08% for Gdiets formulated to 3028 kcal/kg AME. However, this interaction was lost at the end of the growth-out period.
2. For the main effect of dLys, it was observed that Cobb MV × Cobb 500 females fed Gdiets formulated to 1.18% dLys had improvements in d 28 BW, d 14-28 BWG, and FI; d 14-35 BWG and FCR; and d 14-41 FCR. Additionally, feeding ≥1.08% dLys during the grower phase improved d 14-41 BW.
3. For the main effect of AME, feeding Gdiets formulated to 3206 kcal/kg AME resulted in the lowest d 14-28 and 14-35 FI. Also, feeding Cobb MV × Cobb 500

females the Gdiets formulated to ≤3028 kcal/kg AME during the grower phase improved d 14-41 FI and FCR.

4. Feeding Cobb MV × Cobb 500 females the Gdiets formulated to ≥1.08% dLys or ≤3116 kcal/kg AME optimized breast yield (relative to d 42 carcass weight and relative to d 41 live weight). Moreover, there was a stepwise increase in d 42 breast weight when increasing grower dLys levels from 1.00 to 1.18%.
5. Based on our economic analysis using the current market prices for chicken parts and feed ingredients, feeding Cobb MV × Cobb 500 female broilers the Gdiet formulated to 1.18% dLys + 3028 kcal/kg AME was the most profitable at the end of the grow-out period (d 42).

Table 6.1. Diet formulations for grower phase (d 14-28)[1]

Ingredient Name	Digestible lysine (dLys) and apparent metabolizable energy (AME) levels											
	1.00% + 2937 kcal/kg	1.00% + 3028 kcal/kg	1.00% + 3116 kcal/kg	1.00% + 3206 kcal/kg	1.08% + 2937 kcal/kg	1.08% + 3028 kcal/kg	1.08% + 3116 kcal/kg	1.08% + 3206 kcal/kg	1.18% + 2937 kcal/kg	1.18% + 3028 kcal/kg	1.18% + 3116 kcal/kg	1.18% + 3206 kcal/kg
Corn	68.95	68.29	66.45	64.56	66.45	64.57	62.72	60.84	61.80	59.91	58.07	56.18
Soybean meal (48% CP)	27.93	26.96	27.15	27.34	29.86	30.05	30.24	30.43	33.72	33.91	34.10	34.29
Soybean oil	-	1.53	3.17	4.86	0.45	2.13	3.78	5.47	1.21	2.90	4.54	6.23
Defluorinated phosphate	1.24	1.25	1.26	1.26	1.22	1.23	1.24	1.24	1.20	1.20	1.21	1.21
Calcium carbonate	0.584	0.582	0.578	0.573	0.577	0.572	0.567	0.562	0.563	0.558	0.553	0.548
DL-Methionine	0.244	0.257	0.260	0.264	0.291	0.294	0.298	0.301	0.338	0.342	0.345	0.349
L-Lysine HCL	0.148	0.183	0.181	0.180	0.191	0.189	0.187	0.185	0.198	0.196	0.194	0.192
L-Threonine	0.080	0.097	0.098	0.099	0.109	0.110	0.111	0.112	0.125	0.126	0.127	0.128
L-Valine	0.002	0.024	0.026	0.028	0.033	0.035	0.037	0.038	0.046	0.048	0.050	0.052
Phytase[2]	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
Salt, NaCl	0.243	0.242	0.241	0.241	0.244	0.244	0.243	0.243	0.247	0.246	0.246	0.245
Sodium S-Carb	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150
Vitamin-trace mineral	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
Choline Cl-60%	0.086	0.092	0.094	0.095	0.078	0.079	0.080	0.082	0.061	0.062	0.063	0.065
Antibiotic[3]	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Coccidiostat[4]	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Nutrient Name	**Calculated Nutrients (%)[5]**											
AME (kcal/kg)	2937	3028	3116	3206	2937	3028	3116	3206	2937	3028	3116	3206
Crude protein (%)	17.66	17.22	17.18	17.15	18.45	18.42	18.38	18.34	19.95	19.91	19.87	19.83
Crude fat (%)	2.29	3.77	5.36	6.98	2.70	4.32	5.91	7.54	3.39	5.02	6.60	8.23
Linoleic acid (%)	1.42	2.24	3.11	4.01	1.62	2.52	3.39	4.28	1.97	2.86	3.73	4.63
Calcium (%)	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Total phosphorus (%)	0.58	0.57	0.57	0.57	0.58	0.58	0.58	0.57	0.59	0.59	0.59	0.58
Available phosphorus (%)	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Sodium (%)	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Potassium (%)	0.76	0.74	0.73	0.73	0.79	0.79	0.78	0.78	0.85	0.85	0.85	0.84
Chloride (%)	0.22	0.23	0.23	0.23	0.23	0.23	0.23	0.22	0.23	0.23	0.23	0.22
Na+K-Cl (mEq/kg)	227	220	220	220	233	233	233	233	249	249	249	249
Digestible lysine (%)	1.00	1.00	1.00	1.00	1.08	1.08	1.08	1.08	1.18	1.18	1.18	1.18
Digestible methionine (%)	0.50	0.51	0.51	0.51	0.56	0.56	0.56	0.56	0.62	0.62	0.62	0.63
Digestible methionine + Digestible cysteine (%)	0.76	0.76	0.76	0.76	0.82	0.82	0.82	0.82	0.90	0.90	0.90	0.90
Digestible tryptophan (%)	0.19	0.18	0.18	0.18	0.20	0.20	0.20	0.20	0.22	0.22	0.22	0.22
Digestible threonine (%)	0.65	0.65	0.65	0.65	0.70	0.70	0.70	0.70	0.77	0.77	0.77	0.77
Digestible isoleucine (%)	0.69	0.67	0.67	0.67	0.72	0.72	0.72	0.72	0.78	0.78	0.78	0.78
Digestible valine (%)	0.77	0.77	0.77	0.77	0.83	0.83	0.83	0.83	0.91	0.91	0.91	0.91
Digestible arginine (%)	1.08	1.05	1.05	1.05	1.13	1.13	1.13	1.13	1.24	1.24	1.24	1.24
Choline (mg/kg)	1543	1543	1543	1543	1543	1543	1543	1543	1543	1543	1543	1543

[1]Three different digestible lysine (dLys) levels and four different energy (AME) levels were used to create twelve treatments: Trt 1 = 1.00% dLys + 2937 kcal/kg AME; Trt 2 = 1.00% dLys + 3028 kcal/kg AME; Trt 3 = 1.00% dLys + 3116 kcal/kg AME; Trt 4 = 1.00% dLys + 3206 kcal/kg AME; Trt 5 = 1.08% dLys + 2937 kcal/kg AME; Trt 6 = 1.08% dLys + 3028 kcal/kg AME; Trt 7 = 1.08% dLys + 3116 kcal/kg AME; Trt 8 = 1.08% dLys + 3206 kcal/kg AME; Trt 9 = 1.18% dLys + 2937 kcal/kg AME; Trt 10 = 1.18% dLys + 3028 kcal/kg AME; Trt 11 = 1.18% dLys + 3116 kcal/kg AME; Trt 12 = 1.18% dLys + 3206 kcal/kg AME

[2]Ronozyme HiPhos (GT). DSM, Kaiseraugst, Switzerland.

[3]BMD-50 (bacitracin methylene disalicylate). Zoetis, Parsippany, NJ.

[4]Zoamix 25%. Zoetis, Parsippany, NJ.

Table 6.2. Analyzed nutrients for grower feed samples (d 14-28)[1]

Nutrient Name[2]	Digestible lysine (dLys) and apparent metabolizable energy (AME) levels[3]											
	1.00% + 2937 kcal/kg	1.00% + 3028 kcal/kg	1.00% + 3116 kcal/kg	1.00% + 3206 kcal/kg	1.08% + 2937 kcal/kg	1.08% + 3028 kcal/kg	1.08% + 3116 kcal/kg	1.08% + 3206 kcal/kg	1.18% + 2937 kcal/kg	1.18% + 3028 kcal/kg	1.18% + 3116 kcal/kg	1.18% + 3206 kcal/kg
	Avg[4]	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Lysine	1.22	1.16	1.16	1.15	1.18	1.14	1.24	1.30	1.31	1.34	1.40	1.40
Methionine	0.50	0.49	0.54	0.49	0.53	0.50	0.52	0.53	0.55	0.66	0.52	0.61
Cysteine	0.35	0.37	0.36	0.34	0.36	0.34	0.34	0.35	0.37	0.39	0.38	0.36
Methionine + Cysteine	0.85	0.86	0.90	0.83	0.88	0.84	0.86	0.88	0.92	1.05	0.90	0.97
Tryptophan	0.22	0.20	0.19	0.20	0.20	0.21	0.21	0.21	0.23	0.21	0.22	0.22
Threonine	0.79	0.76	0.76	0.74	0.79	0.73	0.79	0.79	0.82	0.80	0.86	0.88
Isoleucine	0.79	0.68	0.71	0.71	0.75	0.71	0.76	0.77	0.77	0.80	0.85	0.84
Valine	0.93	0.87	0.89	0.86	0.89	0.97	0.92	0.90	0.95	0.95	1.01	1.02
Arginine	1.34	1.23	1.24	1.19	1.23	1.20	1.28	1.30	1.35	1.37	1.48	1.46
Taurine	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.10	0.08	0.09	0.09	0.08
Aspartic acid	1.95	1.79	1.81	1.76	1.86	1.73	1.87	1.90	1.96	1.97	2.12	2.14
Serine	0.96	0.89	0.90	0.85	0.92	0.85	0.91	0.92	0.94	0.91	1.01	1.04
Glutamic acid	3.48	3.19	3.23	3.11	3.32	3.11	3.29	3.41	3.49	3.55	3.80	3.82
Proline	1.14	1.12	1.08	1.04	1.09	1.05	1.07	1.08	1.17	1.18	1.18	1.25
Glycine	0.83	0.76	0.77	0.74	0.77	0.73	0.79	0.81	0.82	0.84	0.89	0.88
Alanine	0.96	0.90	0.91	0.88	0.92	0.88	0.93	0.95	0.95	0.97	1.04	1.01
Leucine	1.54	1.39	1.43	1.40	1.49	1.41	1.48	1.48	1.53	1.57	1.65	1.67
Tyrosine	0.52	0.45	0.47	0.46	0.51	0.46	0.53	0.51	0.50	0.52	0.58	0.57
Phenylalanine	0.91	0.81	0.83	0.81	0.86	0.81	0.88	0.91	0.90	0.94	1.00	0.98
Histidine	0.52	0.51	0.49	0.49	0.49	0.47	0.51	0.49	0.51	0.52	0.55	0.56
Gross energy (kcal/kg)	3455	3504	3581	3654	3471	3510	3603	3680	3517	3577	3647	3738
Crude protein	19.68	18.18	18.15	18.95	19.65	18.02	19.07	19.22	19.94	20.30	22.09	21.30

[1]Feed samples were analyzed in duplicate at ATC Scientific labs. North Little Rock, AR. Official Methods of Analysis of AOAC International: Amino acid (AA) by Performic acid (Cysteine and Methionine); AA by Sodium hydroxide (Tryptophan); AA by Hydrochloric acid (all other AA).
[2]W/W%
[3]Dietary treatments were formulated to: Trt 1 = 1.00% digestible lysine (dLys) + 2937 kcal/kg energy (AME); Trt 2 = 1.00% dLys + 3028 kcal/kg AME; Trt 3 = 1.00% dLys + 3116 kcal/kg AME; Trt 4 = 1.00% dLys + 3206 kcal/kg AME; Trt 5 = 1.08% dLys + 2937 kcal/kg AME; Trt 6 = 1.08% dLys + 3028 kcal/kg AME; Trt 7 = 1.08% dLys + 3116 kcal/kg AME; Trt 8 = 1.08% dLys + 3206 kcal/kg AME; Trt 9 = 1.18% dLys + 2937 kcal/kg AME; Trt 10 = 1.18% dLys + 3028 kcal/kg AME; Trt 11 = 1.18% dLys + 3116 kcal/kg AME; Trt 12 = 1.18% dLys + 3206 kcal/kg AME
[4]Average of two analyzed samples/treatment

Table 6.3. Diet formulations for starter (d 0-14) and finisher (d 28-41) phases[1]

Common diet			
Starter (d 0-14)		Finisher (d 28-42)	
Ingredient Name	**Inclusion (%)**	**Ingredient Name**	**Inclusion (%)**
Corn	60.43	**Corn**	63.72
Soybean meal (48% CP)	31.88	**Soybean meal (48% CP)**	24.43
Soybean oil	1.73	**Soybean oil**	3.92
Meat and bone meal (57% CP)	3.50	**Corn DDGS[2]**	5.00
Defluorinated phosphate	0.393	**Defluorinated phosphate**	0.905
Calcium carbonate	0.388	**Calcium carbonate**	0.677
DL-Methionine	0.350	**DL-Methionine**	0.237
L-Lysine HCl	0.223	**L-Lysine HCl**	0.202
L-Threonine	0.177	**L-Threonine**	0.073
L-Valine	0.058	**L-Valine**	-
Phytase[3]	0.011	**Phytase[3]**	0.011
Salt, NaCl	0.285	**Salt, NaCl**	0.270
Sodium S-Carb	0.150	**Sodium S-Carb**	0.150
Vitamin-trace mineral	0.250	**Vitamin-trace mineral**	0.250
Choline Cl-60%	0.060	**Choline Cl-60%**	0.084
Antibiotic[4]	0.050	**Antibiotic[4]**	0.050
Coccidiostat[5]	0.050	**Coccidiostat[5]**	0.050
Nutrient Name	**Calculated Nutrients (%)[6]**	**Nutrient Name**	**Calculated Nutrients (%)[6]**
AME (kcal/kg)	2977	**AME (kcal/kg)**	3151
Crude protein (%)	20.84	**Crude protein (%)**	17.61
Crude fat (%)	4.17	**Crude fat (%)**	6.26
Linoleic acid (%)	2.23	**Linoleic acid (%)**	3.66
Calcium (%)	0.90	**Calcium (%)**	0.76
Total phosphorus (%)	0.60	**Total phosphorus (%)**	0.53
Available phosphorus (%)	0.45	**Available phosphorus (%)**	0.38
Sodium (%)	0.22	**Sodium (%)**	0.22
Potassium (%)	0.82	**Potassium (%)**	0.73
Chloride (%)	0.28	**Chloride (%)**	0.25
Na+K-Cl (mEq/kg)	227	**Na+K-Cl (mEq/kg)**	211
Digestible lysine (%)	1.22	**Digestible lysine (%)**	0.97
Digestible methionine (%)	0.64	**Digestible methionine (%)**	0.50
Digestible methionine + Digestible cysteine (%)	0.92	**Digestible methionine + Digestible cysteine (%)**	0.76
Digestible tryptophan (%)	0.22	**Digestible tryptophan (%)**	0.18
Digestible threonine (%)	0.83	**Digestible threonine (%)**	0.63
Digestible isoleucine (%)	0.79	**Digestible isoleucine (%)**	0.67
Digestible valine (%)	0.94	**Digestible valine (%)**	0.76
Digestible arginine (%)	1.28	**Digestible arginine (%)**	1.02
Choline (mg/kg)	1543	**Choline (mg/kg)**	1543

[1]Common diets were provided to birds during starter (d 0-14) and finisher (d 28-41) phases
[2]Corn distiller's dried grains with solubles
[3]Ronozyme HiPhos (GT). DSM, Kaiseraugst, Switzerland.
[4]BMD-50 (bacitracin methylene disalicylate). Zoetis, Parsippany, NJ.
[5]Zoamix 25%. Zoetis, Parsippany, NJ.
[6]Values are calculated based on the results of nutrients composition of corn, soybean meal, corn DDGs, and animal by-product blend. Feed ingredients for starter diet were analyzed at Missouri University labs (Columbia, MO), and ingredients for finisher diet were analyzed at ATC Scientific labs (North Little Rock, AR)

Table 6.4. Analyzed nutrients for starter (d 0-14) and finisher (d 28-41) feed samples[1]

Nutrient Name[2]	Common diet	
	Starter (d 0-14)	Finisher (d 28-41)
	Avg[3]	Avg
Lysine	1.40	1.09
Methionine	0.59	0.52
Cysteine	0.37	0.34
Tryptophan	0.24	0.17
Threonine	0.94	0.76
Isoleucine	0.85	0.70
Valine	1.07	0.87
Arginine	1.52	1.10
Taurine	0.07	0.07
Aspartic Acid	2.28	1.77
Serine	1.10	0.89
Glutamic Acid	3.93	3.20
Proline	1.42	1.14
Glycine	1.06	0.78
Alanine	1.12	0.95
Leucine	1.71	1.48
Tyrosine	0.57	0.46
Phenylalanine	1.02	0.83
Histidine	0.59	0.50
Gross energy (kcal/kg)	3560.90	3644.25
Crude protein	22.61	18.46

[1]Feed samples were analyzed at ATC Scientific labs. Starter diet was formulated to 1.22% digestible lysine (dLys) + 2977 kcal/kg energy (AME), and finisher diet was formulated to 0.97% dLys + 3151 kcal/kg AME
[2]W/W%
[3]Average of two analyzed samples/diet

Table 6.5. The effect of varying digestible lysine (dLys) and apparent metabolizable energy (AME) levels on d 14-28 Cobb MV × Cobb 500 female performance[1]

Grower dLys level (%)	Grower AME level (kcal/kg)	d 14 Avg[2] BW[3] (kg)	d 28 Avg BW (kg)	d 14-28 BWG[4] (kg)	d 14-28 Avg FI[5]/bird (kg)	d 14-28 FCR[6]	d 14-28 Percent Mortality[7]
1.00	**2937**	0.425	1.421	0.996	1.588	1.595[a]	0
	3028	0.424	1.417	0.994	1.533	1.548[c]	0
	3116	0.424	1.407	0.985	1.518	1.525[d]	0
	3206	0.425	1.425	1.000	1.490	1.491[ef]	0
1.08	**2937**	0.424	1.415	0.990	1.557	1.573[b]	0
	3028	0.424	1.424	1.000	1.535	1.536[cd]	0
	3116	0.424	1.444	1.020	1.503	1.476[f]	0
	3206	0.423	1.446	1.023	1.466	1.433[g]	0
1.18	**2937**	0.423	1.440	1.017	1.520	1.496[e]	0
	3028	0.423	1.473	1.049	1.497	1.426[g]	0
	3116	0.425	1.468	1.044	1.467	1.397[h]	0
	3206	0.423	1.466	1.043	1.451	1.377[i]	0
Marginal means – Grower dLys level							
1.00%		0.424	1.417[b]	0.993[b]	1.535[a]	1.539	0
1.08%		0.424	1.432[b]	1.008[b]	1.516[a]	1.505	0
1.18%		0.423	1.461[a]	1.037[a]	1.484[b]	1.424	0
SEM[8]		0.0004	0.0054	0.0055	0.0076	0.0034	-
Marginal means – Grower AME level							
2937 kcal/kg		0.423	1.425	1.001	1.556[a]	1.552	0
3028 kcal/kg		0.423	1.440	1.016	1.522[b]	1.503	0
3116 kcal/kg		0.425	1.437	1.013	1.496[c]	1.465	0
3206 kcal/kg		0.423	1.444	1.021	1.469[d]	1.434	0
SEM		0.0004	0.0063	0.0063	0.0088	0.0039	-
P-values							
dLys[9]		0.1295	<0.0001	<0.0001	<0.0001	<0.0001	-
AME[10]		0.7198	0.1353	0.1268	<0.0001	<0.0001	-
dLys × AME[11]		0.0981	0.2880	0.3636	0.8935	0.0016	-

[1]Dietary treatments were formulated to: Trt 1 = 1.00% dLys + 2937 kcal/kg AME; Trt 2 = 1.00% dLys + 3028 kcal/kg AME; Trt 3 = 1.00% dLys + 3116 kcal/kg AME; Trt 4 = 1.00% dLys + 3206 kcal/kg AME; Trt 5 = 1.08% dLys + 2937 kcal/kg AME; Trt 6 = 1.08% dLys + 3028 kcal/kg AME; Trt 7 = 1.08% dLys + 3116 kcal/kg AME; Trt 8 = 1.08% dLys + 3206 kcal/kg AME; Trt 9 = 1.18% dLys + 2937 kcal/kg AME; Trt 10 = 1.18% dLys + 3028 kcal/kg AME; Trt 11 = 1.18% dLys + 3116 kcal/kg AME; Trt 12 = 1.18% dLys + 3206 kcal/kg AME
[2]Average
[3]Body Weight (kg)
[4]Body Weight Gain (kg)
[5]Feed Intake/bird (kg)
[6]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[7]Percent Mortality is based on a beginning pen number of 13 birds
[8]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[9]P-values for dLys main effect; alpha set at $P \leq 0.05$
[10]P-values for AME main effect; alpha set at $P \leq 0.05$
[11]P-values for dLys × AME interaction; alpha set at $P \leq 0.05$
[a-c]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 6.6. The carryover effect of feeding grower (d 14-28) diets varying in digestible lysine (dLys) and apparent metabolizable energy (AME) levels on d 14- 35 Cobb MV × Cobb 500 female broiler performance[1]

Grower dLys level (%)	Grower AME level (kcal/kg)	d 35 Avg[2] BW[3] (kg)	d 14-35 BWG[4] (kg)	d 14-35 Avg FI[5]/bird (kg)	d 14-35 FCR[6]	d 14-35 Percent Mortality[7]
1.00	**2937**	1.947	1.522	2.594	1.699^{a}	0
	3028	1.935	1.511	2.485	1.654^{bc}	0
	3116	1.937	1.515	2.484	1.639^{cd}	0
	3206	1.946	1.521	2.459	1.617^{e}	0
1.08	**2937**	1.942	1.517	2.545	1.670^{b}	0.9615
	3028	1.950	1.525	2.508	1.645^{cd}	0
	3116	1.963	1.539	2.466	1.615^{e}	0.9615
	3206	1.966	1.544	2.434	1.577^{f}	0
1.18	**2937**	1.940	1.518	2.487	1.631^{de}	0
	3028	1.993	1.570	2.470	1.574^{fg}	0
	3116	1.984	1.559	2.431	1.564^{fg}	0
	3206	1.975	1.551	2.445	1.556^{g}	0
Marginal means – Grower dLys level						
1.00%		1.943	1.519^{b}	2.510^{a}	1.651	0
1.08%		1.955	1.531^{ab}	2.487^{ab}	1.626	0.4808
1.18%		1.970	1.547^{a}	2.459^{b}	1.578	0
SEM[8]		0.0089	0.0089	0.0130	0.0035	0.1975
Marginal means – Grower AME level						
2937 kcal/kg		1.943	1.519	2.542^{a}	1.667	0.3205
3028 kcal/kg		1.962	1.538	2.489^{b}	1.624	0
3116 kcal/kg		1.957	1.534	2.459^{bc}	1.606	0.3205
3206 kcal/kg		1.962	1.538	2.446^{c}	1.585	0
SEM		0.0102	0.0103	0.0150	0.0040	0.2281
P-values						
Grower dLys[9]		0.0523	0.0471	0.0421	<0.0001	0.1458
Grower AME[10]		0.5090	0.4940	<0.0001	<0.0001	0.5803
Grower dLys × AME[11]		0.6158	0.6613	0.4832	0.0427	0.6835

[1]Common diets were fed to all birds from d 0-14 and 28-41; therefore d 14-35 includes a carryover effect of feeding diets varying in dLys and AME levels from d 14-28. Dietary treatments were formulated to: Trt 1 = 1.00% dLys + 2937 kcal/kg AME; Trt 2 = 1.00% dLys + 3028 kcal/kg AME; Trt 3 = 1.00% dLys + 3116 kcal/kg AME; Trt 4 = 1.00% dLys + 3206 kcal/kg AME; Trt 5 = 1.08% dLys + 2937 kcal/kg AME; Trt 6 = 1.08% dLys + 3028 kcal/kg AME; Trt 7 = 1.08% dLys + 3116 kcal/kg AME; Trt 8 = 1.08% dLys + 3206 kcal/kg AME; Trt 9 = 1.18% dLys + 2937 kcal/kg AME; Trt 10 = 1.18% dLys + 3028 kcal/kg AME; Trt 11 = 1.18% dLys + 3116 kcal/kg AME; Trt 12 = 1.18% dLys + 3206 kcal/kg AME

[2]Average

[3]Body Weight (kg)

[4]Body Weight Gain (kg)

[5]Feed Intake/bird (kg)

[6]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight

[7]Percent Mortality is based on a beginning pen number of 13 birds

[8]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean

[9]P-values for dLys main effect; alpha set at $P \leq 0.05$

[10]P-values for AME main effect; alpha set at $P \leq 0.05$

[11]P-values for dLys × AME interaction; alpha set at $P \leq 0.05$

[a-c]Values within columns with different superscripts differ significantly ($P < 0.05$)

Table 6.7. The carryover effect of feeding grower (d 14-28) diets varying in digestible lysine (dLys) and apparent metabolizable energy (AME) levels on d 14- 41 Cobb MV × Cobb 500 female broiler performance[1]

Grower dLys level (%)	Grower AME level (kcal/kg)	d 41 Avg[2] BW[3] (kg)	d 14-41 BWG[4] (kg)	d 14-41 Avg FI[5]/bird (kg)	d 14-41 FCR[6]	d 14-41 Percent Mortality[7]
1.00	**2937**	2.323	1.898	3.414	1.803	0.9615
	3028	2.335	1.912	3.355	1.756	0.9615
	3116	2.264	1.842	3.313	1.779	0
	3206	2.302	1.877	3.299	1.759	0
1.08	**2937**	2.338	1.913	3.437	1.790	0.9615
	3028	2.354	1.930	3.385	1.756	0
	3116	2.359	1.935	3.381	1.741	0.9615
	3206	2.372	1.950	3.338	1.713	0.9615
1.18	**2937**	2.340	1.917	3.402	1.763	0.9615
	3028	2.401	1.977	3.363	1.701	0.9615
	3116	2.354	1.930	3.296	1.719	0
	3206	2.344	1.922	3.296	1.721	0
Marginal means – Grower dLys level						
1.00%		2.303[b]	1.879[b]	3.349	1.773[a]	0.4808
1.08%		2.356[a]	1.932[a]	3.385	1.750[b]	0.4808
1.18%		2.360[a]	1.936[a]	3.341	1.727[c]	0.4808
SEM[8]		0.0155	0.0156	0.0222	0.0053	0.3451
Marginal means – Grower AME level						
2937 kcal/kg		2.334	1.910	3.426[a]	1.784[a]	0.9615
3028 kcal/kg		2.361	1.937	3.367[ab]	1.737[b]	0.6410
3116 kcal/kg		2.322	1.898	3.330[b]	1.749[b]	0.3205
3206 kcal/kg		2.341	1.917	3.314[b]	1.733[b]	0
SEM		0.0179	0.0180	0.0256	0.0061	0.3985
P-values						
Grower dLys[9]		0.0293	0.0287	0.2801	<0.0001	1.0000
Grower AME[10]		0.4873	0.4989	0.0238	<0.0001	0.3633
Grower dLys × AME[11]		0.7317	0.7548	0.9952	0.0985	0.8558

[1]Common diets were fed to all birds from d 0-14 and 28-41; therefore d 14-41 includes a carryover effect of feeding diets varying in dLys and AME levels from d 14-28. Dietary treatments were formulated to: Trt 1 = 1.00% dLys + 2937 kcal/kg AME; Trt 2 = 1.00% dLys + 3028 kcal/kg AME; Trt 3 = 1.00% dLys + 3116 kcal/kg AME; Trt 4 = 1.00% dLys + 3206 kcal/kg AME; Trt 5 = 1.08% dLys + 2937 kcal/kg AME; Trt 6 = 1.08% dLys + 3028 kcal/kg AME; Trt 7 = 1.08% dLys + 3116 kcal/kg AME; Trt 8 = 1.08% dLys + 3206 kcal/kg AME; Trt 9 = 1.18% dLys + 2937 kcal/kg AME; Trt 10 = 1.18% dLys + 3028 kcal/kg AME; Trt 11 = 1.18% dLys + 3116 kcal/kg AME; Trt 12 = 1.18% dLys + 3206 kcal/kg AME
[2]Average
[3]Body Weight (kg)
[4]Body Weight Gain (kg)
[5]Feed Intake/bird (kg)
[6]Feed Conversion Ratio (Feed:Gain) was adjusted with mortality weight
[7]Percent Mortality is based on a beginning pen number of 13 birds
[8]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[9]P-values for dLys main effect; alpha set at $P \leq 0.05$
[10]P-values for AME main effect; alpha set at $P \leq 0.05$
[11]P-values for dLys × AME interaction; alpha set at $P \leq 0.05$
[a-c]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 6.8. The effect of varying digestible lysine (dLys) and apparent metabolizable energy (AME) levels from d 14-28 on d 42 processing characteristics reported as average yield relative to d 41 live weight[1]

Grower dLys level (%)	Grower AME level (kcal/kg)	d 41 Avg[2] BW[3] (kg)	Yield relative to d 41 live weight (%)[4]						
			Carcass	Breast[5]	Tender[6]	Drumstick	Thigh	Wing	Fat Pad
1.00	**2937**	2.310	70.474	17.687	4.1857	9.833	12.292	8.016	1.758
	3028	2.313	69.985	17.252	4.252	9.606	12.011	7.992	1.553
	3116	2.267	70.472	17.419	4.137	9.803	12.025	8.092	1.687
	3206	2.293	70.635	17.229	4.231	9.649	12.078	7.983	1.794
1.08	**2937**	2.336	70.336	18.104	4.195	9.426	11.894	7.998	1.597
	3028	2.351	70.583	18.212	4.167	9.468	11.923	7.998	1.665
	3116	2.322	70.177	17.781	4.200	9.488	12.217	7.975	1.830
	3206	2.362	70.126	17.832	4.112	9.407	12.259	7.949	1.737
1.18	**2937**	2.332	70.892	18.817	4.257	9.448	11.922	7.886	1.592
	3028	2.417	70.586	18.774	4.190	9.452	12.086	7.998	1.548
	3116	2.366	70.474	18.191	4.203	9.655	12.398	7.968	1.490
	3206	2.356	70.256	17.569	4.161	9.645	12.103	8.087	1.577
Marginal means – Grower dLys level									
1.00%		2.292[b]	70.404	17.403[b]	4.203	9.722[a]	12.103	8.021	1.698[a]
1.08%		2.343[a]	70.306	17.982[a]	4.168	9.447[b]	12.073	7.980	1.707[a]
1.18%		2.368[a]	70.552	18.363[a]	4.203	9.550[b]	12.127	7.985	1.552[b]
SEM[7]		0.0161	0.1449	0.1503	0.0351	0.0538	0.0842	0.0439	0.0358
Marginal means – Grower AME level									
2937 kcal/kg		2.326	70.568	18.203[a]	4.212	9.569	12.036	7.967	1.649
3028 kcal/kg		2.361	70.384	18.079[a]	4.203	9.509	12.007	7.996	1.589
3116 kcal/kg		2.314	70.391	17.823[ab]	4.181	9.644	12.221	8.012	1.667
3206 kcal/kg		2.337	70.339	17.542[b]	4.167	9.567	12.146	8.006	1.702
SEM		0.0185	0.1673	0.1736	0.0405	0.0622	0.0972	0.0506	0.0413
P-values									
Grower dLys[8]		0.0083	0.4754	0.0002	0.7335	0.0023	0.9020	0.7764	0.0038
Grower AME[9]		0.4013	0.7676	0.0417	0.8574	0.4767	0.4110	0.9254	0.2629
Grower dLys × AME[10]		0.8005	0.4587	0.4896	0.8331	0.6048	0.3548	0.7588	0.1522

[1]Common diets were fed to all birds from d 0-14 and 28-41; therefore, processing characteristics at d 42 (reported as average yield relative to d 41 live weight) are a carryover effect of feeding diets varying in dLys and AME levels from d 14-28. Dietary treatments were formulated to: Trt 1 = 1.00% dLys + 2937 kcal/kg AME; Trt 2 = 1.00% dLys + 3028 kcal/kg AME; Trt 3 = 1.00% dLys + 3116 kcal/kg AME; Trt 4 = 1.00% dLys + 3206 kcal/kg AME; Trt 5 = 1.08% dLys + 2937 kcal/kg AME; Trt 6 = 1.08% dLys + 3028 kcal/kg AME; Trt 7 = 1.08% dLys + 3116 kcal/kg AME; Trt 8 = 1.08% dLys + 3206 kcal/kg AME; Trt 9 = 1.18% dLys + 2937 kcal/kg AME; Trt 10 = 1.18% dLys + 3028 kcal/kg AME; Trt 11 = 1.18% dLys + 3116 kcal/kg AME; Trt 12 = 1.18% dLys + 3206 kcal/kg AME
[2]Average
[3]Body Weight (kg)
[4]Yield relative to d 41 live weight (%)
[5]Breast refers to the pectoralis major
[6]Tender refers to the pectoralis minor
[7]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[8]P-values for dLys main effect; alpha set at $P \leq 0.05$
[9]P-values for AME main effect; alpha set at $P \leq 0.05$
[10]P-values for dLys × AME interaction; alpha set at $P \leq 0.05$
[a-c]Values within columns with different superscripts differ significantly ($P < 0.05$)

Table 6.9. The effect of varying digestible lysine (dLys) and apparent metabolizable energy (AME) levels from d 14-28 on d 42 processing characteristics reported as average yield relative to d 42 carcass weight[1]

Grower dLys level (%)	Grower AME level (kcal/kg)	Carcass wt[2] (kg)	Yield relative to d 42 carcass weight[3] (%)					
			Breast[4]	Tender[5]	Drumstick	Thigh	Wing	Fat Pad
1.00	**2937**	1.626	25.030	5.941	13.936	17.421	11.396	2.492
	3028	1.619	24.650	6.077	13.723	17.194	11.443	2.219
	3116	1.614	24.666	5.835	13.911	17.095	11.467	2.419
	3206	1.620	24.385	5.999	13.662	17.101	11.290	2.546
1.08	**2937**	1.643	25.732	5.964	13.406	16.918	11.374	2.272
	3028	1.659	25.798	5.904	13.419	16.896	11.331	2.359
	3116	1.629	25.334	6.014	13.526	17.403	11.358	2.633
	3206	1.656	25.411	5.858	13.415	17.482	11.337	2.478
1.18	**2937**	1.653	26.495	6.007	13.328	16.835	11.131	2.248
	3028	1.707	26.634	5.936	13.379	17.123	11.317	2.206
	3116	1.668	25.825	5.984	13.713	17.627	11.321	2.116
	3206	1.655	24.980	5.917	13.736	17.220	11.541	2.247
Marginal means – Grower dLys level								
1.00%		1.619[b]	24.683[b]	5.963	13.803[a]	17.203	11.399	2.419[a]
1.08%		1.647[ab]	25.569[a]	5.935	13.442[b]	17.175	11.350	2.436[a]
1.18%		1.671[a]	26.016[a]	5.961	13.539[b]	17.201	11.328	2.204[b]
SEM[6]		0.0121	0.1876	0.0480	0.0810	0.1204	0.0630	0.0509
Marginal means – Grower AME level								
2937 kcal/kg		1.640	25.753[a]	5.971	13.557	17.058	11.300	2.337
3028 kcal/kg		1.662	25.694[a]	5.972	13.507	17.071	11.364	2.261
3116 kcal/kg		1.637	25.275[ab]	5.944	13.707	17.375	11.382	2.390
3206 kcal/kg		1.644	24.923[b]	5.923	13.604	17.268	11.389	2.424
SEM		0.0139	0.2166	0.0554	0.0935	0.1390	0.0728	0.0588
P-values								
Grower dLys[7]		0.0137	<0.0001	0.8991	0.0062	0.9832	0.7178	0.0027
Grower AME[8]		0.6017	0.0296	0.9188	0.4447	0.3004	0.8189	0.2371
Grower dLys × AME[9]		0.8697	0.5489	0.5459	0.5382	0.2484	0.4757	0.1503

[1]Common diets were fed to all birds from d 0-14 and 28-41; therefore, processing characteristics at d 42 (reported as average yield relative to carcass weight) are a carryover effect of feeding diets varying in dLys and AME levels from d 14-28. Dietary treatments were formulated to: Trt 1 = 1.00% dLys + 2937 kcal/kg AME; Trt 2 = 1.00% dLys + 3028 kcal/kg AME; Trt 3 = 1.00% dLys + 3116 kcal/kg AME; Trt 4 = 1.00% dLys + 3206 kcal/kg AME; Trt 5 = 1.08% dLys + 2937 kcal/kg AME; Trt 6 = 1.08% dLys + 3028 kcal/kg AME; Trt 7 = 1.08% dLys + 3116 kcal/kg AME; Trt 8 = 1.08% dLys + 3206 kcal/kg AME; Trt 9 = 1.18% dLys + 2937 kcal/kg AME; Trt 10 = 1.18% dLys + 3028 kcal/kg AME; Trt 11 = 1.18% dLys + 3116 kcal/kg AME; Trt 12 = 1.18% dLys + 3206 kcal/kg AME
[2]Carcass weight (kg)
[3]Yield relative to carcass weight (%)
[4]Breast refers to the pectoralis major
[5]Tender refers to the pectoralis minor
[6]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[7]P-values for dLys main effect; alpha set at $P \leq 0.05$
[8]P-values for AME main effect; alpha set at $P \leq 0.05$
[9]P-values for dLys × AME interaction; alpha set at $P \leq 0.05$
[a-c]Values within columns with different superscripts differ significantly ($P < 0.05$)

Table 6.10. The effect of varying digestible lysine (dLys) and apparent metabolizable energy (AME) levels from d 14-28 on d 42 processing characteristics reported as average weight[1]

Grower dLys level (%)	Grower AME level (kcal/kg)	Avg[2] weight (kg)					
		Breast[3]	Tender[4]	Drumstick	Thigh	Wing	Fat Pad
1.00	**2937**	0.408	0.097	0.227	0.283	0.185	0.041
	3028	0.399	0.098	0.222	0.278	0.184	0.036
	3116	0.398	0.094	0.224	0.276	0.185	0.039
	3206	0.395	0.097	0.221	0.277	0.183	0.041
1.08	**2937**	0.426	0.098	0.221	0.280	0.186	0.037
	3028	0.428	0.098	0.223	0.280	0.188	0.039
	3116	0.411	0.097	0.219	0.284	0.184	0.043
	3206	0.421	0.097	0.222	0.290	0.188	0.041
1.18	**2937**	0.439	0.099	0.220	0.278	0.184	0.037
	3028	0.456	0.101	0.228	0.292	0.193	0.038
	3116	0.429	0.099	0.228	0.293	0.188	0.037
	3206	0.415	0.099	0.225	0.285	0.190	0.037
Marginal means – Grower dLys level							
1.00%		0.400[c]	0.096	0.223	0.279	0.184	0.039[ab]
1.08%		0.422[b]	0.098	0.221	0.283	0.187	0.040[a]
1.18%		0.436[a]	0.100	0.225	0.287	0.189	0.037[b]
SEM[5]		0.0049	0.0010	0.0016	0.0024	0.0013	0.0009
Marginal means – Grower AME level							
2937 kcal/kg		0.424	0.098	0.223	0.280	0.185	0.038
3028 kcal/kg		0.427	0.099	0.224	0.283	0.188	0.037
3116 kcal/kg		0.412	0.097	0.224	0.284	0.186	0.039
3206 kcal/kg		0.411	0.098	0.223	0.284	0.187	0.040
SEM		0.0057	0.0012	0.0019	0.0029	0.0015	0.0010
P-values							
Grower dLys[6]		<0.0001	0.0868	0.1908	0.0529	0.0549	0.0462
Grower AME[7]		0.0975	0.5590	0.9147	0.7411	0.4254	0.3747
Grower dLys × AME[8]		0.5429	0.9720	0.4284	0.2244	0.4651	0.1537

[1]Common diets were fed to all birds from d 0-14 and 28-41; therefore, processing characteristics at d 42 (reported as average weight) are a carryover effect of feeding diets varying in dLys and AME levels from d 14-28. Dietary treatments were formulated to: Trt 1 = 1.00% dLys + 2937 kcal/kg AME; Trt 2 = 1.00% dLys + 3028 kcal/kg AME; Trt 3 = 1.00% dLys + 3116 kcal/kg AME; Trt 4 = 1.00% dLys + 3206 kcal/kg AME; Trt 5 = 1.08% dLys + 2937 kcal/kg AME; Trt 6 = 1.08% dLys + 3028 kcal/kg AME; Trt 7 = 1.08% dLys + 3116 kcal/kg AME; Trt 8 = 1.08% dLys + 3206 kcal/kg AME; Trt 9 = 1.18% dLys + 2937 kcal/kg AME; Trt 10 = 1.18% dLys + 3028 kcal/kg AME; Trt 11 = 1.18% dLys + 3116 kcal/kg AME; Trt 12 = 1.18% dLys + 3206 kcal/kg AME
[2]Average
[3]Breast refers to the pectoralis major
[4]Tender refers to the pectoralis minor
[5]Standard Error of the Mean, an estimate of the amount that an obtained mean may be expected to differ by chance from the true mean
[6]P-values for dLys main effect; alpha set at $P \leq 0.05$
[7]P-values for AME main effect; alpha set at $P \leq 0.05$
[8]P-values for dLys × AME interaction; alpha set at $P \leq 0.05$
[a-c]Values within columns with different superscripts differ significantly ($P<0.05$)

Table 6.11. Potential gross bird profit or potential saving for each grower digestible lysine (dLys) and apparent metabolizable energy (AME) level

Potential gross chicken part values[1] using processing data (chicken parts weight in kg) and chicken part values in the market (cents)[2]	**dLys and AME levels fed in grower phase (d 14-28)[3]**											
	1.00% + 2937 kcal/kg	**1.00% + 3028 kcal/kg**	**1.00% + 3116 kcal/kg**	**1.00% + 3206 kcal/kg**	**1.08% + 2937 kcal/kg**	**1.08% + 3028 kcal/kg**	**1.08% + 3116 kcal/kg**	**1.08% + 3206 kcal/kg**	**1.18% + 2937 kcal/kg**	**1.18% + 3028 kcal/kg**	**1.18% + 3116 kcal/kg**	**1.18% + 3206 kcal/kg**
Breast	95.98	93.88	93.65	93.10	100.34	100.81	96.66	99.20	103.36	107.31	101.00	97.72
Wing	63.69	63.48	63.67	62.86	64.20	64.69	63.48	64.66	63.25	66.47	64.80	65.39
Tender	37.19	37.82	36.07	37.29	37.73	37.73	37.31	37.40	38.16	38.90	38.23	38.11
Thigh	22.26	21.81	21.70	21.75	21.96	22.04	22.35	22.75	21.86	22.94	23.01	22.41
Drumstick	12.66	12.40	12.49	12.35	12.35	12.43	12.24	12.40	12.29	12.75	12.75	12.58
Total potential gross chicken part values/bird (cents)[4]	231.78	229.39	227.59	227.35	236.57	237.69	232.05	236.40	238.92	248.36	239.79	236.21
Total feed costs/bird (cents)[5]	91.23	90.62	91.61	92.95	93.191	93.68	78.72	95.14	94.24	94.97	94.53	98.05
Total feed costs/bird (dollars)[6]	0.912	0.906	0.916	0.930	0.932	0.937	0.787	0.951	0.942	0.950	0.945	0.981

Table 6.11 (continued)

Gross bird profit (profit processing-feed costs/bird; cents)[7]	140.55	138.77	135.98	134.40	143.38	144.00	153.33	141.26	144.69	153.39	145.26	138.16
Gross bird profit (profit processing-feed costs/bird; dollars; kg)[8]	1.406	1.388	1.360	1.344	1.434	1.440	1.533	1.413	1.447	1.534	1.453	1.382

[1]Potential gross chicken part values = Processing data (chicken parts wt in kg) * Chicken part value in the market (cents)
[2]USDA (report for January, 2019. Chicken part prices (cents/kg): Breast = 235.44; Wings = 344.36; Tenderloins = 384.60; Thighs = 78.57; Drumsticks = 55.84)
[3]Dietary treatments were formulated to: Trt 1 = 1.00% dLys + 2937 kcal/kg AME; Trt 2 = 1.00% dLys + 3028 kcal/kg AME; Trt 3 = 1.00% dLys + 3116 kcal/kg AME; Trt 4 = 1.00% dLys + 3206 kcal/kg AME; Trt 5 = 1.08% dLys + 2937 kcal/kg AME; Trt 6 = 1.08% dLys + 3028 kcal/kg AME; Trt 7 = 1.08% dLys + 3116 kcal/kg AME; Trt 8 = 1.08% dLys + 3206 kcal/kg AME; Trt 9 = 1.18% dLys + 2937 kcal/kg AME; Trt 10 = 1.18% dLys + 3028 kcal/kg AME; Trt 11 = 1.18% dLys + 3116 kcal/kg AME; Trt 12 = 1.18% dLys + 3206 kcal/kg AME. These dietary treatments were provided to birds during the grower phase (d 14-28), and common starter and finisher diets were fed to all birds from d 0-14 and 28-41, respectively.
[4]Total potential gross chicken part value/bird (cents) = sum of the potential gross chicken part values (breast, wings, tenders, thighs, and drumsticks) per bird
[5]Total feed cost/bird (cents) = Average feed intake (kg) * Feed cost (cents/kg; ingredient prices were based from Feedstuffs - Ingredient Market Prices and USDA. Ingredient prices ($/ton): corn = $149.60; soybean meal = $309.00; deflourinated phosphate = $1,675.51; calcium carbonate = $233.69; salt = $65.00; soybean oil = $747.79; sodium S-carb = $557.77; vitamin-trace mineral = $2,336.90; DL-methionine = $2,744.75; L-lysine = $1,741.65; L-threonine = $2,006.20; L-valine = $10,913.07; phytase = $9,146.60; antibiotic = $8,664.16; coccidiostat = $989.60)
[6]Total feed cost/bird (dollars) = Total feed cost/bird (cents) / 100
[7]Gross bird profit (cents) = Total potential gross profit/bird (cents) – Total feed cost/bird (cents)
[8]Gross bird profit (dollars; in kg) = Gross bird profit (cents) /100

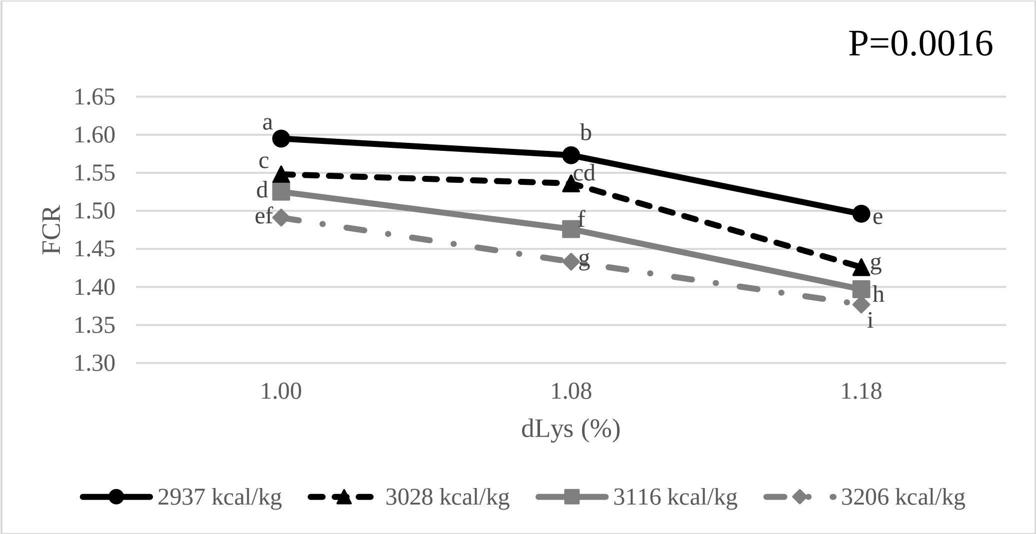

Figure 6.1. Digestible lysine (dLys) × Apparent metabolizable energy (AME) interaction for d 14-28 feed conversion ratio (FCR)[1]

[1]Dietary treatments were formulated to: Trt 1 = 1.00% dLys + 2937 kcal/kg AME; Trt 2 = 1.00% dLys + 3028 kcal/kg AME; Trt 3 = 1.00% dLys + 3116 kcal/kg AME; Trt 4 = 1.00% dLys + 3206 kcal/kg AME; Trt 5 = 1.08% dLys + 2937 kcal/kg AME; Trt 6 = 1.08% dLys + 3028 kcal/kg AME; Trt 7 = 1.08% dLys + 3116 kcal/kg AME; Trt 8 = 1.08% dLys + 3206 kcal/kg AME; Trt 9 = 1.18% dLys + 2937 kcal/kg AME; Trt 10 = 1.18% dLys + 3028 kcal/kg AME; Trt 11 = 1.18% dLys + 3116 kcal/kg AME; Trt 12 = 1.18% dLys + 3206 kcal/kg AME
[a-c]Means within a column not sharing a common superscript differ (P<0.05)

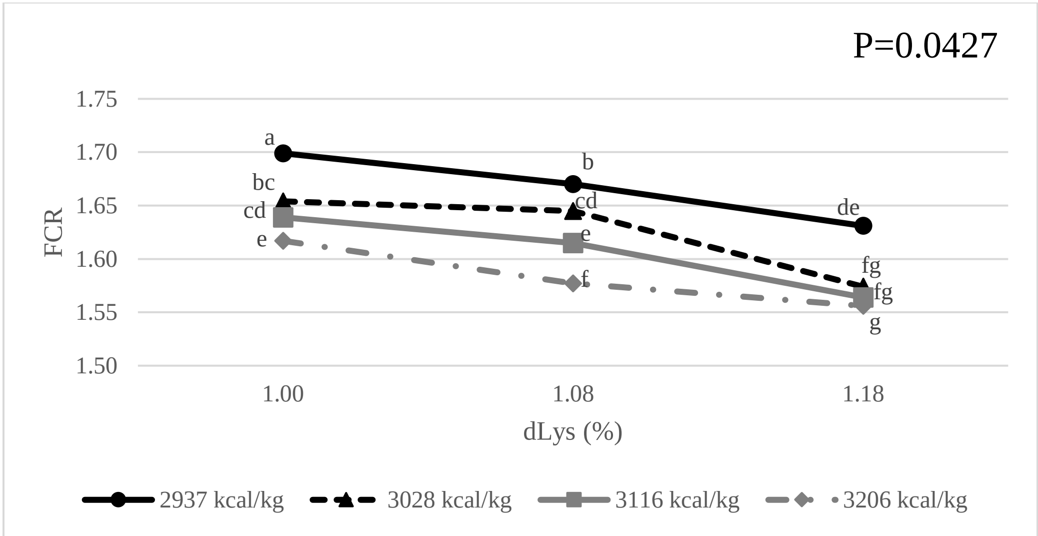

Figure 6.2. Digestible lysine (dLys) × Apparent metabolizable energy (AME) interaction for d 14-35 feed conversion ratio (FCR)[1]

[1]Dietary treatments were formulated to: Trt 1 = 1.00% dLys + 2937 kcal/kg AME; Trt 2 = 1.00% dLys + 3028 kcal/kg AME; Trt 3 = 1.00% dLys + 3116 kcal/kg AME; Trt 4 = 1.00% dLys + 3206 kcal/kg AME; Trt 5 = 1.08% dLys + 2937 kcal/kg AME; Trt 6 = 1.08% dLys + 3028 kcal/kg AME; Trt 7 = 1.08% dLys + 3116 kcal/kg AME; Trt 8 = 1.08% dLys + 3206 kcal/kg AME; Trt 9 = 1.18% dLys + 2937 kcal/kg AME; Trt 10 = 1.18% dLys + 3028 kcal/kg AME; Trt 11 = 1.18% dLys + 3116 kcal/kg AME; Trt 12 = 1.18% dLys + 3206 kcal/kg AME
[a-c]Means within a column not sharing a common superscript differ ($P<0.05$)

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