Optimizing broiler performance using different amino acid density diets: What are the limits?¹

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Primary Audience: Nutritionists, Broiler Integrators

SUMMARY

Broiler responses of economic interest, such as BW gain, FCR, and breast meat yield (BMY), can be optimized by increasing amino acid (AA) concentrations, improving the AA balance, or both. The AA requirements to maximize a response are lowest for BW gain, increased for FCR, and highest for BMY. A maximum performance response is reached when the response plateaus, whereas an optimal response is the one providing the highest return per input. These are usually not the same. Strategies used in linear feed formulation differ in how dietary AA are included in the diet; therefore, understanding how these strategies affect broiler responses is necessary to compare ultimate potential benefits. Minimum CP restrictions are still used even when TSAA, Lys, and Thr restrictions are set simultaneously, and AA requirements are presently expressed as either total or digestible. The use of ratios of essential AA to Lys is more popular now that synthetic Thr has become commercially available, and it will likely have an increase in use when L-valine and L-isoleucine have competitive prices. The present-day high-yield broiler has an increased responsiveness to AA density, especially for Lys, which contrasts with published requirements still in use. Increasing Lys and other AA at the beginning of the bird’s life has been shown to have some positive carryover effects on performance in later periods; however, increasing the Lys and essential AA in broiler diets in the last phases of production allows compensation for BMY because of the continuous high allometric growth rate of breast muscle. Gains in performance are expected to result from increases in dietary AA density; however, the decision regarding what AA density to use will depend on the cost of feed relative to the market price of meat.

Key words: amino acid density, broiler, meat yield

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REVIEW OF LITERATURE

The progress experienced by the broiler industry in the last decades has been marked by impressive improvements in all areas of management, health, and nutrition, but genetics has been the area mostly responsible for improvements in the live performance and meat yields of...
broilers. At least 85% of the improvements seen in live performance between 1959 and 2001 can be attributed to selection for BW gain (BWG), FCR, and breast meat yields (BMY) [1]. Comparisons made between chicken lines not selected since 1940 (UIUC Heritage line maintained at the University of Illinois, Champaign) and a 2007 Ross 708 commercial broiler resulted in increases, at 34 d of age, of 72% in BW and 3.4 times more BMY [2]. Two major changes that affect the physiology of bird growth were observed in the Ross 708 broiler: 1) breast muscles maintained a positive allometric growth after 34 d of age, and 2) there was a 20% increase in the intestinal surface as compared with the 1940 line [2]. The first finding translates into higher requirements for amino acids (AA), especially Lys, whereas the second could partially explain improvements in FCR other than those achieved simultaneously with the heavier BW at an earlier age.

The rapid growth rate of the present-day broiler requires increased amounts of all nutrients and energy on a daily basis, but these demands for different nutrients are not in the same proportions as previous ones. Amino acid requirements increase proportionately faster than do energy requirements; thus, a higher AA-to-energy ratio is required in faster growing strains of broilers [3]. Morris and Njuru [4] fed diets with increasing protein content to broilers and to laying-type cockerels and observed that BWG and body protein content in cockerels were maximized with diets having considerably less protein than in the diets of broilers. In that study, broilers continued to benefit from the additional dietary protein to achieve a heavier BW. This was likely due to the continued tissue growth, especially of breast muscles.

Dietary AA concentrations should match needs for both maintenance and skeletal muscle accretion to effectively allow for increased synthesis of white meat [5]. In the last few years, it has been demonstrated that providing dietary protein above the concentrations used by the US industry leads to improved FCR and BMY in different genetic strains [5–8]. Benefits of diets with an increased AA density have been shown when applied early in life as well as in the finisher phases. Feeding diets containing high AA concentrations can result in greater economic returns if implemented in the starter phase, a period when feed intake is relatively low and growth rate is high [5], because some of the benefits appear to have a carryover effect throughout growth to market age [9, 10]. Increasing Lys and other essential AA only in the finisher diet has also been shown to improve FCR and BMY [11] when compared with diets with average AA densities, such as those currently used in the United States. This latter approach takes advantage of the positive allometric growth of breast muscles compared with other body tissues at later ages.

**Feed Formulation Approaches to Provide Dietary AA**

Linear least-cost feed formulation software is used widely to provide economic solutions with minima set for specific nutrients. However, major differences exist among the formulation approaches that nutritionists take to formulate dietary protein in feeds. This can affect the concentrations and balance of the AA formulated into the diet and can potentially affect the ability of the broiler to express its capacity for growth and muscle deposition. Some of these differences are related to whether AA requirements are expressed as total or digestible, which becomes more important as the diet complexity increases in terms of ingredient composition. Further formulation differences can result if digestible AA values are expressed on a true or apparent basis, with the first providing higher numeric values because endogenous losses have been accounted for. Maintaining ingredient matrixes within the same basis of expression reduces the spread between the expected inclusion levels of AA and the actual levels delivered in the feed, resulting in a tool that allows for more exact formulation. Regardless of the AA nomenclature used, many nutritionists establish minimum CP restrictions during feed formulation, which provides a safety net for maintaining minimum essential as well as nonessential AA concentrations without specifically defining what these are. Formulating diets with the use of the ideal protein concept (AA-to-Lys ratios) allows for greater precision in formulation and ensures that a balanced AA profile is formulated that optimizes performance and yields. This formulating approach has been increasing in use among nutritionists, and it tar-
gets the reduction in imbalances between the first- or second-limiting AA and other dietary AA. Imbalances have negative effects because they lead to metabolic costs associated with the oxidation of AA that are available in the diet and that are absorbed but are in excess of needs. With the use of the ideal protein concept, it is possible to maintain an AA balance in practical situations throughout the life of the bird.

*Feeding High-AA Diets Earlier vs. Later in Life*

**Importance of an Early Provision of AA.** Embryos hatch with a myofiber number that, given normal circumstances, is not expected to change after hatch. Growth of muscle after hatch occurs through increases in fiber size, which are paralleled by increases in the number of nuclei per myofiber [12]. A group of myogenic precursor cells, called the satellite cells, are found between the muscle cell and its plasmalemma. These myogenic precursor cells can multiply and later fuse with adjacent fibers, aggregating more nuclei and thereby having a greater capacity for protein synthesis [13]. It is estimated that 98% of the final DNA content of muscle results from this process [14]. However, an actual increase in myofiber size can be achieved only by a concurrent and balanced supply of dietary AA.

Muscle protein deposition is the difference between protein synthesis and protein degradation. The efficiency of protein retention and deposition is strongly affected by age. Breast muscle deposition is as high as 68% in the first week and is only 23% at 6 wk of age [15]. Protein synthesis is still increasing linearly at 6 wk of age, but the increase in protein degradation is higher than that of protein synthesis, resulting in a net reduction in protein accretion as the bird ages [15]. Accretion of body protein depends on hormonal balance, which displays specific concentration patterns depending on age. Chicken relative growth rate and age-related changes in plasma concentrations of insulin-like growth factor, insulin-like growth factor 1 (IGF-I), and thyroxin are highly correlated. The peaks of these hormones in broilers have been reported to occur between 3 and 6 wk of age [16], and also at this time, protein degradation has been shown to present a sharp increase [15]. Vandenburgh et al. [17] observed that muscle cells incubated with IGF-I exhibited a marked increase in protein synthesis and that this occurred in parallel with a decrease in protein degradation. Dietary protein has also been shown to regulate IGF-I concentrations in broilers [18] and, as such, may be a mediator for the powerful regulatory influence of protein on muscle growth and protein turnover [19]. Circulating IGF-I concentrations have been shown to decrease in broilers fed low-protein diets [20]. Urdaneta-Rincon and Leeson [21] demonstrated, in broilers, that as dietary CP increased from 21 to 25%, a positive effect was observed on protein synthesis as well as in protein retention. Increasing the Lys concentration within both CP concentrations resulted in further improvement in protein retention in the higher (25%) CP diet.

The early posthatch period is considered an opportunity for the preparation of the mechanisms that will control the overall capacity of body protein deposition. This period is frequently considered a window of opportunity to affect muscle growth and, if missed, decreases the ability to profoundly affect muscle deposition later in life. Immediate posthatch feeding is critical for the appropriate morphological development of the pectoralis major muscle in broiler chickens, the formation of intramuscular fat depots, and the expression of the genes necessary for muscle cell proliferation and differentiation [22]. Imposing feed restriction immediately after hatch to reduce growth by 20% was reported to lead to a negative effect on breast muscle development at 28 d [22]. Permanent losses in the capacity for muscle accretion have been clearly demonstrated in broilers when a 2-d fasting period was imposed early [9]. Broilers were fasted either from 0 to 2 d, 2 to 4 d, 4 to 6 d, or 6 to 8 d of age, and it was observed that the closer the fasting was to the time of hatch, the greater the negative effect on BWG and BMY at later ages. Broiler chickens fasted on d 4 to 6 posthatch had BWG and BMY at 42 d of age similar to those that were not fasted, whereas those fasted from d 0 to 2 d posthatch had lower BWG and BMY [9]. However, broilers fasted or fed for 3 d immediately after hatching with diets formulated with 0.82, 0.99, 1.16, or 1.33% digestible Lys had increased satellite cell mitotic activity
compared with birds that were provided a Lys-deficient diet [23]. This seems to be in contrast to the response expected under fasting circumstances, but it may provide an opportunity for implementing early nutritional imprinting that could result in a greater capacity for muscle growth later in life.

**Optimizing the Benefits of Feeding Higher AA Concentrations in Later Growth Phases.** Broiler genetic selection has changed the patterns of muscle growth and development from hatch to sexual maturity. However, the overall developmental pattern of muscles, with a much earlier development of the legs in contrast to a later development of the breast, as seen in wild precocial birds, is still present in the modern-day broiler chicken. In meat-producing species, such as the broiler chicken, describing the relative growth of a muscle group is always of interest to match the processing age with market needs. Allometry is the study of the relative growth of body parts (i.e., the proportional and differential changes in the sizes of the different body components) and has been used to compare the relative growth of body components [24]. In general, comparisons are done between the growth of 1 body component and the growth of the whole body. A case in point is the relative growth equation of Huxley [25] of \( Y = \alpha(X^\beta) \), where \( Y \) is the mass of the body component, \( X \) is the mass of the whole body, \( \alpha \) is a constant that reflects the relationship between the 2, and \( \beta \) is the rate of change of the body component with changes in the total body mass.

Throughout the growing cycle, broiler chickens exhibit a high allometric growth ratio for breast muscles (1.36) compared with the growth of drumsticks (1.10) and thighs (1.06) [26]. At 14 to 35 d of age (1,804 g of BW at 35 d), commercial broilers exhibited allometric growth rates of breast muscle compared with the whole body of 1.25, whereas birds not selected for BMY had a ratio of 1.09 [2]. Therefore, the breast muscles of broilers are still growing at greater rates than the total body or legs when they begin reaching market ages. This means that at later ages, AA are still expected to be in high demand for breast muscle growth, whereas demands for whole-body or leg growth are lower and are used almost exclusively to support maintenance.

The increased pressure to reduce the effect of feed costs on live production frequently leads to reductions in AA supplementation in commercial feeds at the end of the broiler growing cycle because this is where feed intake is highest. This strategy, in general, affects breast muscle accretion negatively. It has been shown that broilers consuming diets using average industry concentrations of AA respond to the supplementation of dietary Lys in the last weeks before processing, but this response is related to strains and their capacity for BMY [27]. The increased amount of breast muscle as a proportion of the total body in high-yield broilers suggests a higher demand for Lys in the later growth phases. Actually, increasing the Lys concentration in the feeds of broilers as well as of slower growing laying hens leads to greater proportions of Lys in the total body protein, although a greater effect is observed in broilers [28]. The response of broilers to diets with higher AA densities provided later in life is obviously also dependent on the concentrations of the other essential AA. The destination of the different AA is dependent on the actual demands for tissue synthesis as well as for maintenance. As broilers age and maintenance AA requirements represent a larger proportion of total AA needs, the balance among AA required to maximize growth changes [29]. At least for the first limiting AA, maintenance needs of the total AA requirements are minimal for young birds, and they increase substantially as the birds become heavier with increases in age [29]. On the basis of recent data, the Lys requirement for maintenance may be substantially greater than previously thought, bringing into question the validity of increasing the ratio of AA to Lys during later growth periods [30]. At least for TSAA, maintenance needs may explain the reasons for greater FCR and BMY responses with increased TSAA. The TSAA do not even reach a plateau at a 77% ratio with Lys in 35-d-old male broilers [31] because the TSAA maintenance requirements are at least twice as those for Lys [32].

**Feeding Regimens with High AA Densities: Economic Evaluations**

General nutrient recommendations for broilers are supposed to allow for appropriate growth. However, dietary AA concentrations
that optimize broiler responses can be different depending on the production goals. For instance, with increased concentrations of TSAA, greater returns are obtained for BMY than for BWG or carcass yield, and these responses are dependent on broiler genetics [31, 33, 34]. Although breast meat is presently the main commercial target for broiler meat production in the United States, dietary AA supplementation has to take into consideration factors such as the desired market weight, product mix, live broiler cost, and genetics. Diets formulated for low AA densities that minimize the feed cost can limit broiler meat accretion and negatively affect profitability, especially when consideration is given to BMY and breast meat prices [35]. In many other markets around the world, broilers are marketed as whole carcasses or breast meat has no added value when compared with leg quarters. In these markets, FCR and BWG are the most important targets, and, to a certain extent, dietary AA densities that optimize economic responses in these latter markets can be lower.

Because feed costs account for the largest proportion of total broiler production costs, the volatility and dramatic changes in ingredient costs in recent years have added pressure on nutritionists to focus on reducing feed costs. This frequently cannot be achieved without performance losses. Furthermore, meat production may actually have an increased total production cost under low-cost feeding programs.

There is an interest today in optimizing FCR and BMY responses through the use of higher AA density diets, as opposed to minimizing feed costs. However, to allow fair comparisons between feed formulations in different broiler production systems, AA concentrations in feeds have to follow similar feed formulation standards. For instance, increases in Lys have to be followed along with increases in TSAA and Thr or with minimum restrictions of CP; otherwise, performance will be hindered by the next-limiting AA. Economic evaluations of broiler responses obtained with the use of high AA density diets and comparisons of economic returns are also difficult because meat product mixes change depending on market demands.

Feed costs associated with FCR and BMY, or any other production objective, could represent a simplified way of comparing economic responses obtained under different feeding regimens. In comparing diets with different AA densities, one can objectively check whether the improved performance obtained with high AA density diets outweighs the higher dietary costs. At least experimentally, this type of evaluation has been done. Coneglian et al. [36] formulated diets using the Brazilian Tables [37] as reference concentrations for Lys (moderate concentration), or a 12% increase (high concentration) or reduction (low concentration) in Lys vs. the moderate concentration. Diets were corn- and SBM-based diets (all vegetable) and had 1.25, 1.19, 1.09, and 1.05% digestible Lys in the moderate-concentration starter, grower, finisher, and withdrawal diets. Ratios of TSAA to Lys were maintained at 73 and 75% from 1 to 21 d and 21 to 40 d, respectively, and those for Thr to Lys were maintained at 65% to the end of the 40-d study. Both Cobb × Cobb 500 feather-sexable broilers and Ross × Ross 308 broilers responded favorably in terms of FCR and BMY at 34 and 40 d. The feed cost associated with the bird responses measured showed that the moderate-concentration diets provided the best return at 34 and 40 d. In a similar study using Cobb × Cobb 500 fast-feathering broilers, Corzo et al. [8] also evaluated the effects of diets varying in AA density on live performance, BMY, and associated feed production costs. They used moderate AA density diets (moderate concentration) in a 3-phase feeding program (1 to 14 d, 14 to 28 d, and 28 to 42 d) having 1.16, 1.03, and 0.97% digestible Lys and minimum ratios of digestible TSAA and Thr of 78 and 62%, respectively, throughout the diets. The low and high AA density diets (approximately 9% higher and lower in Lys than the moderate diet) were formulated, and several combinations of diet densities were tested. Costs were optimized with different dietary programs depending on the response evaluated: BW was maximized when the low-low-moderate diet combination was used, whereas FCR was maximized with the low-low-low diet combination and BMY was maximized with the high-high-high diet combination.

As with any other economic decision, knowledge of the consequences of changing inputs on outcomes is paramount. Whether AA density should be increased or decreased is dependent on the ability to quickly estimate the effect of
moving in either of these directions. Because broiler meat production is a highly competitive business, each integrator should have reliable data regarding the effect of changing AA balances and densities in the diets to adapt to the frequent changes in the cost of feeds, the demand for product mixes, and the changes in meat market prices.

CONCLUSIONS AND APPLICATIONS

1. Comparisons of broiler responses to diets with different AA densities have to take into account the feed formulation methods used (total vs. digestible AA, true vs. apparently digestible AA, AA-to-Lys ratios, CP minima or not).

2. The density of AA presently provided to broilers may not maximize all performance responses.

3. Increasing the AA density in diets fed early in life provides some carryover benefits in performance; however, increasing the AA density later could be a profitable strategy when performance is not maximized early.

4. The economics of AA density with broilers has to take into account improvements obtained in live performance and meat yields as well as the sales market price of each specific product mix.

REFERENCES AND NOTES


fed graded levels of lysine and crude protein. Poult. Sci. 83:1897–1903.


