Effects of Dynamic Amino Acid Supply on Growth Performance, Slaughter Performance, Nutrient Intake, and Intestinal Development in Broilers: Postprint

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Abstract

This experiment aimed to investigate the effects of subdivided dietary amino acid supply on growth performance, slaughter performance, nutrient intake, and intestinal development of broiler chickens based on a broiler amino acid requirement model. A total of 192 one-day-old Arbor Acres (AA) male broiler chicks were selected and randomly divided into 4 groups: Group A (2-phase), Group B (3-phase), Group C (6-phase), and Group D (12-phase), with 6 replicates per group and 8 birds per replicate, for a 42-day experimental period. The results showed: 1) The average daily gain (ADG) of broilers in Group A was significantly higher than that in Groups B, C, and D ($P<0.05$). There was no significant difference in average daily feed intake (ADFI) among Groups A, B, and C ($P>0.05$), all of which were significantly higher than Group D ($P<0.05$). The feed-to-gain ratio (F/G) of broilers in Group A was significantly lower than that in Groups B, C, and D ($P<0.05$). 2) The slaughter rate of broilers in Group B was significantly higher than that in Groups A, C, and D ($P<0.05$). The eviscerated yield of broilers in Group B was significantly higher than that in Groups C and D ($P<0.05$), with no significant difference from Group A ($P>0.05$). The breast muscle percentage of broilers in Group A was significantly higher than that in Groups B, C, and D ($P<0.05$). The abdominal fat percentage of broilers in Group A was significantly lower than that in Groups B, C, and D ($P<0.05$). 3) The metabolizable energy intake of broilers in Group D was significantly lower than that in Groups A, B, and C ($P<0.05$). The crude protein and lysine intake of broilers in Group A was significantly higher than that in Groups B, C, and D ($P<0.05$), and the crude protein and lysine intake of broilers in Groups B and C was significantly higher than that in Group D ($P<0.05$). The methionine intake of broilers in Group A was significantly higher than that in Groups B and D (P<0.05). The sulfur-containing amino acid intake of broilers in Group A was significantly higher than that in Groups B and D (P<0.05). The threonine intake of broilers in Group D was significantly lower than that in Groups A and C (P<0.05). 4) The duodenal villus height and villus height-to-crypt depth ratio (V/C) of broilers in Group A were significantly higher than those in Groups B, C, and D (P<0.05). There were no significant differences in jejunal and ileal villus height, crypt depth, and V/C values among all groups (P>0.05). 5) At 42 days of age, the body weight of broilers in Group A was significantly higher than that in Groups B, C, and D (P<0.05), and the body weight of broilers in Groups B and C was significantly higher than that in Group D (P<0.05). There was no significant difference in cost per unit weight gain of broilers among Groups B, C, and D compared with Group A (P>0.05). In summary, 2-phase feeding can promote duodenal development and increase nutrient intake in broiler chickens. Considering growth performance, slaughter performance, and cost per unit weight gain comprehensively, the 2-phase feeding regimen is recommended for broiler chickens.

Full Text

Effects of Dynamic Amino Acid Supply on Growth Performance, Carcass Performance, Nutrient Intakes and Intestinal Development of Broilers

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Abstract

This experiment was conducted to investigate the effects of subdivided dietary amino acid supply on growth performance, carcass performance, nutrient intakes and intestinal development of broilers based on amino acid requirement models. A total of 192 one-day-old Arbor Acres (AA) male broilers were randomly assigned to 4 groups: Group A (2 phases), Group B (3 phases), Group C (6 phases) and Group D (12 phases), with 6 replicates per group and 8 birds per replicate. The trial lasted for 42 days. The results showed that: 1) Average daily gain (ADG) of broilers in Group A was significantly higher than those in Groups B, C and D (P<0.05). Average daily feed intake (ADFI) among Groups A, B and C showed no significant differences (P>0.05), but all were significantly higher than that in Group D (P<0.05). The feed-to-gain ratio (F/G) of broilers in Group A was significantly lower than those in Groups B, C and D (P<0.05). 2) Slaughter rate of broilers in Group B was significantly higher than those in Groups A, C and D (P<0.05). Eviscerated percentage of broilers in Group B was significantly higher than those in Groups C and D (P<0.05), while showing no significant difference compared with Group A (P>0.05). Breast muscle percentage of broilers in Group A was significantly higher than those in Groups B, C and D (P<0.05). Abdominal fat percentage of broilers in Group A was significantly lower than those in Groups B, C and D (P<0.05). 3) Metabolizable energy intake of broilers in Group D was significantly lower than those in Groups A, B and C (P<0.05). Crude protein and lysine intakes of broilers in Group A were significantly higher than those in Groups B, C and D (P<0.05), and those in Groups B and C were significantly higher than in Group D (P<0.05). Methionine intake of broilers in Group A was significantly higher than those in Groups B and D (P<0.05). Sulfur-containing amino acid intake of broilers in Group A was significantly higher than those in Groups B and D (P<0.05). Threonine intake of broilers in Group D was significantly lower than those in Groups A and C (P<0.05). 4) Duodenal villus height and villus height/crypt depth (V/C) ratio of broilers in Group A were significantly higher than those in Groups B, C and D (P<0.05). No significant differences were observed among groups in villus height, crypt depth and V/C ratio in jejunum and ileum (P>0.05). 5) At 42 days of age, body weight of broilers in Group A was significantly higher than those in Groups B, C and D (P<0.05), while body weights in Groups B and C were significantly higher than in Group D (P<0.05). No significant differences were found in cost per unit weight gain among Groups B, C and D compared with Group A (P>0.05). In conclusion, 2-phase feeding can promote duodenal development and improve nutrient intake in broilers. Considering growth performance, carcass performance and cost per unit weight gain comprehensively, a 2-phase feeding regimen is recommended for broiler production.

Keywords: broilers; dynamic amino acids; growth performance; carcass performance; intestine development

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Introduction

Current feeding standards in various countries define nutrient requirements as static values for specific production or growth stages under relatively fixed environmental conditions [1]. With the deepening of modern animal nutrition research, "dynamic nutrition technology" has been widely applied in diet formulation for monogastric animals including pigs, poultry and aquatic animals, playing an important role in improving animal production performance, reducing production costs, decreasing nitrogen and phosphorus excretion, and ensuring product quality and safety [2]. Dynamic nutrition aims to approximate the true nutrient requirements of animals through precise diet formulation and feeding techniques based on their needs under different growth stages, environmental conditions and production objectives [3].

As a major animal-producing country, China places broiler production in a very important position within its animal agriculture sector, and dietary nutrient supply plays a critical role in broiler growth. Protein costs account for a substantial proportion of broiler feed costs [4], and dietary protein functions through amino acids and their biological roles [5]. Therefore, it is necessary to study the effects of dynamic dietary amino acid supply on broiler growth and development. Warren et al. [6] formulated diets based on the linear amino acid requirement model for broilers established by Emmert et al. [7] and found that, compared with feeding according to NRC (1994) recommendations, broiler growth performance showed no significant differences during 1-21 days and 40-61 days of age, and carcass yield also remained unaffected. Brewer et al. [8] reported that compared with feeding at industry-average nutrient levels, multi-stage precision feeding did not adversely affect weight gain, feed conversion ratio or carcass yield, but significantly reduced production costs. Using Arbor Acres (AA) broilers as experimental subjects, this study aimed to investigate the effects of dynamic amino acid supply on growth performance, carcass performance, nutrient intakes and small intestinal mucosal structure, thereby providing a theoretical basis for multi-stage precision feeding to improve production efficiency.

1.1 Experimental Animals and Location

One-day-old AA male broilers were purchased from Beijing Kangda Poultry Company. The feeding trial was conducted in an environmentally controlled facility at the Changping Base of the Institute of Animal Sciences, Chinese Academy of Agricultural Sciences, Beijing.

1.2 Experimental Design and Diets

This experiment employed a single-factor completely randomized design. A total of 192 healthy one-day-old AA male broilers were randomly allocated to 4 groups with 6 replicates each and 8 birds per replicate. Initial body weights among replicates showed no significant differences ($P>0.05$).

Group A: 2 phases (1-3 weeks and 4-6 weeks). Diet formulation referenced the "Nutrient Requirements for Broiler Chickens" in NY/T 33—2004, primarily considering dietary levels of metabolizable energy, crude protein, lysine, methionine, methionine + cysteine, and threonine.

Group B: 3 phases (1-2 weeks, 3-4 weeks, and 5-6 weeks).

Group C: 6 phases (1 phase per week).

Group D: 12 phases (1 phase per 3.5 days).

For Groups B, C and D, dietary amino acid levels were calculated according to Tian Yadong [9], primarily considering dietary lysine, methionine, methionine + cysteine, and threonine levels. Tian Yadong [9] determined amino acid levels for each stage by calculating the ratio of amino acid requirement to metabolizable energy requirement for a specific growth stage based on established broiler amino acid requirement models. Metabolizable energy was fixed as a constant value for each growth stage, and dietary amino acid levels were then calculated by multiplying this ratio by the fixed metabolizable energy value. Since this study focused on dynamic dietary amino acid supply, Groups B (during 1-2 and 5-6 weeks), C and D (during 1-3 and 4-6 weeks) were fed diets consistent with Group A in metabolizable energy, calcium, phosphorus and other nutrients, except for crude protein and amino acid levels. For Group B during 3-4 weeks, metabolizable energy, calcium, phosphorus and other nutrient levels were based on NY/T 33—2004 "Feeding Standard of Chickens," taking the average values for 1-3 and 4-6 weeks to maintain consistency in nutrients other than amino acids and crude protein across groups as much as possible. To ensure precise calculation of dietary amino acid levels, this study referenced rooster experimental data, whereas Tian Yadong [9] used data from mixed-sex populations in his calculations. Feed ingredient amino acid levels were measured before diet formulation. Temperature, humidity and lighting were strictly controlled according to AA broiler rearing standards to ensure consistent environmental conditions across replicates. During diet changes every 3.5 days, residual feed was completely removed from all four groups before providing new feed. Birds had ad libitum access to feed and water, and were vaccinated according to standard procedures. Diet composition and nutrient levels for each group are presented in Table 1 , Table 2 , Table 3 and Table 4 .

1.3.1 Growth Performance

Broilers were weighed by replicate on day 1. On day 42, broilers were weighed by replicate after 12 hours of feed withdrawal (with water provided). Feed consumption was recorded every 3.5 days for each group to calculate average daily gain (ADG), average daily feed intake (ADFI) and feed-to-gain ratio (F/G).

1.3.2 Carcass Performance

On day 42, 12 broilers were randomly selected from each group (2 birds per replicate), weighed, slaughtered, and then measured for carcass weight, eviscerated carcass weight, breast muscle weight, leg muscle weight and abdominal fat weight to calculate slaughter rate, eviscerated percentage, breast muscle percentage, leg muscle percentage and abdominal fat percentage.

Calculation formulas were as follows: - Slaughter rate (%) = 100 × carcass weight / live weight - Eviscerated percentage (%) = 100 × eviscerated carcass weight / live weight - Breast muscle percentage (%) = 100 × breast muscle weight / eviscerated carcass weight - Leg muscle percentage (%) = 100 × leg muscle weight / eviscerated carcass weight - Abdominal fat percentage (%) = 100 × abdominal fat weight / (eviscerated carcass weight + abdominal fat weight)

1.3.3 Nutrient Intakes at 42 Days

Feed intake was accurately recorded every 3.5 days by replicate. Based on the nutrient levels of the diets consumed during the corresponding growth stages, nutrient intakes over 42 days were calculated using the following formula:

Nutrient intake over 42 days = Σ[3.5 × average daily feed intake (3.5 d) × nutrient content of corresponding diet].

1.3.4 Small Intestinal Mucosal Structure

On day 42, 6 broilers with body weights close to the group average were selected from each group (1 bird per replicate) and slaughtered. Approximately 1.5 cm segments from the middle portion of duodenum, jejunum and ileum were immediately excised, rinsed with freshly prepared physiological saline, and rapidly fixed in 4% formaldehyde solution. Fixed tissues were processed through dehydration, embedding, sectioning, baking, xylene dewaxing, hydration, staining and mounting before microscopic examination. Data were measured using Image-Pro Plus 7.0 software. Measurements included villus height and crypt depth, with 5 fields of view per slide averaged as the final result. The villus height/crypt depth (V/C) ratio was calculated (villus height: vertical distance from intestinal gland opening to villus tip; crypt depth: vertical distance from crypt opening to crypt base).

1.3.5 Body Weight and Cost per Unit Weight Gain

Cost per unit weight gain was calculated based on initial and final body weights using the following formula:

Cost per unit weight gain = Σ[3.5 × average daily feed intake (3.5 d) × cost of corresponding diet] / average body weight gain.

1.4 Statistical Analysis

Experimental data were expressed as mean ± standard deviation. One-way ANOVA was performed using SPSS 19.0 software to test for significant differences among groups, with Duncan' s multiple range test used for post-hoc comparisons. Significance level was set at $P<0.05$.

Results

2.1 Effects of Dynamic Amino Acid Supply on Growth Performance

The effects of dynamic amino acid supply on broiler growth performance are shown in Table 5 . Broiler ADG in Group A was significantly higher than those in Groups B, C and D ($P<0.05$), while ADG in Groups B and C was significantly higher than in Group D ($P<0.05$). No significant difference in ADG was observed between Groups B and C ($P>0.05$). ADFI among Groups A, B and C showed no significant differences ($P>0.05$), but all were significantly higher than that in Group D ($P<0.05$). The F/G ratio of broilers in Group A was significantly lower than those in Groups B, C and D ($P<0.05$), and F/G in Group B was significantly lower than in Group D ($P<0.05$), with no significant difference between Groups B and C ($P>0.05$).

2.2 Effects of Dynamic Amino Acid Supply on Carcass Performance

The effects of dynamic amino acid supply on broiler carcass performance are presented in Table 6 . Slaughter rate of broilers in Group B was significantly higher than those in Groups A, C and D ($P<0.05$), while no significant differences were observed among Groups A, C and D ($P>0.05$). Eviscerated percentage of broilers in Group B was significantly higher than those in Groups C and D ($P<0.05$), with no significant difference compared to Group A ($P>0.05$). Breast muscle percentage of broilers in Group A was significantly higher than those in Groups B, C and D ($P<0.05$). No significant differences in leg muscle percentage were found among groups ($P>0.05$). Abdominal fat percentage of broilers in Group A was significantly lower than those in Groups B, C and D ($P<0.05$), and abdominal fat percentages in Groups B and C were significantly lower than in Group D ($P<0.05$), with no significant difference between Groups B and C ($P>0.05$).

2.3 Effects of Dynamic Amino Acid Supply on Nutrient Intakes

The effects of dynamic amino acid supply on broiler nutrient intakes are shown in Table 7 . Metabolizable energy intake of broilers in Group D was significantly lower than those in Groups A, B and C ($P<0.05$), while no significant differences were observed among Groups A, B and C ($P>0.05$). Crude protein and lysine intakes of broilers in Group A were significantly higher than those in Groups B, C and D ($P<0.05$), and intakes in Groups B and C were significantly higher than in Group D ($P<0.05$), with no significant difference between Groups B and C ($P>0.05$). Methionine intake of broilers in Group A was significantly higher than those in Groups B and D ($P<0.05$), while no significant differences were found among Groups B, C and D ($P>0.05$). Sulfur-containing amino acid intake of broilers in Group A was significantly higher than those in Groups B and D ($P<0.05$), with no significant difference compared to Group C ($P>0.05$). Threonine intake of broilers in Group D was significantly lower than those in Groups A and C ($P<0.05$), but showed no significant difference compared to Group B ($P>0.05$).

2.4 Effects of Dynamic Amino Acid Supply on Small Intestinal Mucosal Structure

The effects of dynamic amino acid supply on duodenal mucosal structure of broilers are presented in Table 8 . Duodenal villus height and V/C ratio of broilers in Group A were significantly higher than those in Groups B, C and D ($P<0.05$), while no significant differences were observed among Groups B, C and D for these parameters ($P>0.05$). No significant differences in duodenal crypt depth were found among groups ($P>0.05$).

The effects of dynamic amino acid supply on jejunal mucosal structure of broilers are shown in Table 9 . No significant differences were observed among groups in jejunal villus height, crypt depth or V/C ratio ($P>0.05$).

The effects of dynamic amino acid supply on ileal mucosal structure of broilers are presented in Table 10 . No significant differences were observed among groups in ileal villus height, crypt depth or V/C ratio (P>0.05).

2.5 Effects of Dynamic Amino Acid Supply on Body Weight and Cost per Unit Weight Gain

The effects of dynamic amino acid supply on broiler body weight and cost per unit weight gain are shown in Table 11 . No significant differences were observed in 1-day-old body weight among groups (P>0.05). At 42 days of age, body weight of broilers in Group A was significantly higher than those in Groups B, C and D (P<0.05), while body weight in Group D was significantly lower than those in Groups B and C (P<0.05). No significant differences in cost per unit weight gain were observed among Groups B, C and D compared with Group A (P>0.05), but cost per unit weight gain in Group B was significantly lower than in Group D (P<0.05).

Discussion

3.1 Effects of Dynamic Amino Acid Supply on Growth Performance

Saki et al. [4] investigated three feeding programs (NRC 1994, single-stage nutrition supply, and multi-stage nutrition supply) using Cobb and AA broilers, reporting that AA broilers fed according to NRC (1994) standards exhibited optimal growth performance. Brewer et al. [10] examined the effects of two different amino acid supply strategies on growth performance of three broiler strains during 18-32 days of age, concluding that dynamic amino acid supply did not negatively affect and could even improve growth performance across strains. However, another study by Brewer et al. [11] found inconsistent effects of multi-stage amino acid supply on growth performance among different broiler strains. Qiu Dianrui et al. [12] studied the effects of 2-, 3- and 6-phase nutrition supply on Ross 308 broiler performance, demonstrating that 3-phase nutrition supply significantly improved ADG and reduced F/G. Zhang Jie [13] reported that under an ideal amino acid model, weekly feeding compared with conventional feeding showed no significant differences in body weight gain, feed intake or feed conversion ratio during 1-49 days. The current study results indicate that as the number of feeding phases increased, broiler ADG tended to decrease while ADFI and F/G tended to increase, which is consistent with Saki et al. [4] in that feeding according to currently accepted nutrition standards yielded the best growth performance. Two possible explanations exist: First, broilers exhibit compensatory growth [14], meaning that even if relatively fixed nutrition standards result in insufficient nutrient supply during early stages, broilers can still achieve satisfactory growth performance through compensatory growth during later stages. Second, as feeding phases become increasingly subdivided, the frequency of dietary nutrient level changes accelerates, creating a stress response in broilers that intensifies with each change and consequently negatively impacts growth performance.

3.2 Effects of Dynamic Amino Acid Supply on Carcass Performance

Warren et al. [6] studied the effects of three phase-feeding strategies on carcass performance of Cobb broilers, reporting no significant effects on eviscerated percentage, breast muscle percentage or leg muscle percentage, but finding that abdominal fat percentage was significantly lower with NRC (1994) feeding compared with the Illinois Ideal Chick Protein (IICP) model, though not significantly different from weekly feeding based on ideal amino acid equations. Brewer et al. [11] demonstrated that conventional feeding compared with multi-stage amino acid supply improved breast muscle percentage, though the magnitude of improvement varied among strains. The current results show that 2-phase feeding according to China' s "Feeding Standard of Chickens" significantly improved breast muscle percentage and reduced abdominal fat percentage compared with other groups, which is consistent with previous research. Studies have shown that abdominal fat content is significantly negatively correlated with dietary crude protein level [15-17]. In this experiment, the overall crude protein level in the 2-phase diet was higher than in the other three groups, which likely contributed to the lower abdominal fat percentage observed.

3.3 Effects of Dynamic Amino Acid Supply on Nutrient Intakes

Nutrient intake is critically important for animal growth and development. Warren et al. [6] reported that three different dynamic amino acid supply strategies showed no significant effects on lysine, sulfur-containing amino acid or threonine intakes during 1-21 days, but during 40-61 days, feeding according to NRC (1994) resulted in significantly higher lysine and threonine intakes compared with IICP and weekly feeding based on ideal amino acid equations. These findings align with the current study, where 2-phase feeding yielded the highest intakes of crude protein, lysine, methionine, sulfur-containing amino acids and threonine. Additionally, Huang Jinxiu et al. [18] reported that flocks with maximum ADG typically exhibited maximum feed intake, which is consistent with our results.

3.4 Effects of Dynamic Amino Acid Supply on Small Intestinal Mucosal Structure

Gastrointestinal development and function significantly influence nutrient digestion and utilization. Small intestinal villi are the primary mucosal structures, and their length, crypt depth and V/C ratio are important indicators of digestive and absorptive function [19]. Caspary [20] demonstrated that increased villus height and V/C ratio along with decreased crypt depth indicate enhanced intestinal digestive and absorptive function. Limited research exists on the effects of dynamic amino acid supply on intestinal development. Sun Jianli et al. [21] reported that dietary crude protein level did not affect duodenal, jejunal or ileal development in Luxi game chickens. However, Hao Ruirong et al. [22] found that excessively high dietary crude protein levels inhibited absolute growth of intestinal villi of different lengths. In the current study, no significant differences were observed among groups in jejunal or ileal mucosal structure parameters, which is consistent with Sun Jianli et al. [21]. However, 2-phase feeding significantly improved duodenal villus height and V/C ratio compared with other treatments, indicating better intestinal development. This may be attributed to greater total nutrient intake stimulating duodenal development, though the specific mechanisms require further investigation.

3.5 Effects of Dynamic Amino Acid Supply on Body Weight and Cost per Unit Weight Gain

Tian Yadong [9] found that diet formulation based on model predictions combined with weekly feeding could reduce weight gain costs. Zhang Jie [13] reported that using an ideal amino acid model with weekly feeding did not significantly affect 42-day body weight. Brewer et al. [11] demonstrated that refined amino acid supply according to ideal amino acid models reduced weight gain costs compared with conventional feeding standards, though the reduction magnitude varied among strains, and while not adversely affecting final body weight across three strains, it significantly reduced final body weight in one strain. The current results partially align with Brewer et al. [11], showing that feeding according to China' s 2004 "Feeding Standard of Broilers" (2-phase nutrition supply) produced the highest final body weight. However, subdividing amino acid supply phases did not reduce cost per unit weight gain compared with 2-phase feeding. The lack of cost reduction may be related to the price settings for various feed ingredients, particularly corn, soybean meal and amino acids, used in diet cost calculations.

Conclusion

Two-phase feeding can promote duodenal development and improve nutrient intake in broilers. Considering growth performance, carcass performance and cost per unit weight gain comprehensively, a 2-phase feeding regimen is recommended for broiler production.

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Note: Figure translations are in progress. See original paper for figures.