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Functional Roles of Branched-Chain Amino Acids in Poultry Nutrition and Health: A Review

Mohammed Hasib Mohamed [1], Ruya. F. Jasim [2]
[1] Department of Animal Production, College of Agriculture, Kirkuk University, Kirkuk, Iraq.
[2] College of Nursing, Kirkuk University, Kirkuk, Iraq

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Annotation: We reviewed the physiological/functional roles of BCAAs (i.e. leucine, isoleucine and valine) in poultry and poultry health in the present review. As such, BCAA is a substrate for protein synthesis as well as an anabolic regulator and acts also as a systemic metabolic/physiological modulator. This also explains the improvement in broiler growth performance, feed efficiency as well as carcass traits and egg production and quality of laying hens as a result of dietary supplementation with BCAAs. Furthermore, BCATs are important for functions such as immunity, gut health, and microbiota homeostasis, and they reduce adverse effects of heat stress or oxidative stress perturbations. But, if the ratios are unbalanced or further accompanied with high leucine content, antagonistic effects are probable and they may negatively impact performance. The paper articulates opportunities for the precision feeding, the assignment of nanoencapsulation technology and genetic approach to enhance the utilization of BCAAs are described for the sustainable poultry production.

Keywords: leucine; isoleucine; valine; gut health; oxidative stress; performance.

Introduction

Amino acids represent one of the three fundamental nutrients in diet. They constitute fundamental constructs of protein and are required for the synthesis of quality muscle tissues, metabolic enzyme activities tissue repair. In addition to their role in incorporation into polypeptides by bonding to one another by peptide bonds, amino acids have important regulatory functions and play a significant role in controlling many and perhaps most metabolic pathways affecting immunity, reproduction, and health status. Leucine, isoleucine and valine should be considered separately, these BCAAs have distinct metabolic roles and hence are considered especially important in terms of poultry muscle physiology. BCAAs are the most abundant group of EAAs and have characteristic as they are mainly metabolized in the skeletal muscle as well as they are also metabolized in the liver, or kidney, or pancreas to a lesser extent.

Recently, certain studies have given an insight of the importance of minerals and natural bioactive compounds in relation to animal health, such as oxidative stress related to lead, molybdenum as well as the biochemical and kid behaviors and responses to selenium and zinc in sheep and cannabis seed whole powder antioxidants and saffron antioxidants in relation to behaviors and oxidative stress in livestock. In addition, other studies have reported that the effects of hormonal treatment on the reproduction performance and certain blood physiological and biochemical parameters may give a satellite insight on the effects of the drug responses on the productivity of the farm animals. It has been found in the previous researches that dietary BCAA supplementation improves growth performance, feed efficiency, and muscles growth. Some reports has already been conducted to prove that muscle protein synthesis and carcass yield improves with the BCAAs in balanced concentration of leucine, isoleucine and valine. Special attention was paid to review indicating that BCAAs had the ability to improve the immunity host by modulating anti-inflammatory factors while also showing strong antioxidant effects to relieve the stress of high-efficiency poultry production. It was already positively reported that the reviews that are now addressing not only the benches and test tubes but are also covering the wider economic context. It has been suggested in the reviews pertaining to housing crises or the policies of foreign loans that, too, can have indirect pathological relationships of influence. The latter frequently force countries into a path of development of least resistance, a kind of fiscal pathway of least resistance. This review aims to provide additional insights on the roles of BCAAs in the poultry nutrition and health performance. Abstract: The article will specifically focus on their biochemical and physiological functions linked to growth and immunity/health performance and discuss prospective for its adoption in sustainable poultry production systems.

Metabolism and Physiological Functions of BCAAs

Digestive Process, Absorption, and Transportation of BCAAs in Poultry

Similar to mammals, protein digestion begins in the proventriculus and gizzard of birds in which hydrocloric acid (HCl) and pepsin causes the protein hydrolysis to start [29]. In the small intestine, pancreatic proteases breakdown peptide, freeing amino acids and branched-chain amino acids (BCAAs). L-Leucine, L-Isoleucine and L-Valine are absorbed mainly in the jejunum by sodium-dependent or sodium-independent transporters such as system (Nie et al., 2021).

In contrast to the vast majority of the amino acids in the diet, which are extensively catabolized in the liver, BCAAs are spared significant hepatic metabolism and enter the blood stream in large part by the free blood amino acid pool directly. The peripheral tissues (notably skeletal muscle due to their potential need for muscle protein synthesis and energy as well (Shimomura et al, 2006) favor their supply. This metabolic vitalization makes BCAAs represent arguably the most categorically indispensible nutrients for birds regarding growth and muscle tissue accretion.

Responsibility in Protein Synthesis & Energy Production

BCAAs are important regulators of protein metabolism in avian species, and leucine is the most potent mTOR signaling activator [17]. Such improvement in translation initiation via this pathway seems to promote muscle protein accretion, representing the characteristic rapid growth of broiler (Kim et al., 2022). In addition to its anabolic role, BCAAs are energy substrates in states of stress or undernutrition [10]. First, the EAAs are transaminated to form the BCKAs by branched-chain aminotransferase (BCAT). The intermediates are further oxidized to produce acetyl-CoA and succinyl-CoA by branched chain α-keto acid dehydrogenase (BCKDH), and feed into the TCA cycle for ATP generation (Wu, 2013). Such metabolic plasticity permits BCAAs to promote both robustness and growth, dependent on production conditions.

Metabolic Pathways Interactions with Other Amino Acids

Genomic and proteomic studies have revealed that BCAA metabolism is tightly interconnected with the metabolism of other amino acids and metabolic pathways (129–134). The distorted dietary ratios of leucine:isoleucine and leucine:valine subsequently result in adverse consequences on growth and feed efficiency (EFSA FEEDAP Panel 2023b). Kidd et al. (2017) noted that high concentrations of leucine can impair valine and isoleucine use and that BCAA-to-lysine ratios are important for maximizing performance of broilers.

Being proteinogenic and competing in terms of permeability across the blood-brain barrier with other aromatic amino acids that are neurochemically similar to BCAAs (e.g. tryptophan), BCAAs have classical competition for the same transport system [13]. The effect of competition on neurotransmitters is fairly significant and stressors in chicken (Eeckhaut et al. Moreover, BCAA catabolism end-products such as keto-isocaproate are implicated in both lipid metabolism and anti-oxidation, reaffirming the pleiotropic role of BCAAs beyond being merely proteinogenic amino acids (Jian et al., 2021).

Effects of BCAAs on Poultry Performance

Growth Rate and Feed Efficiency

Branched chain amino acids (BCAAs) are an important signal molecules and have also a key role on protein synthesis and feed application in poultry. Improvement in Muscle Protein Accretion and Feed Efficiency A balanced ratio of leucine:isoleucine:valine vs lysine promotes muscle protein accretion mediated by the mTOR pathway (Kim et al., 2022). Nevertheless, due to the antagonistic action of leucine in relation to valine and isoleucine, it might have a negative effect on growth performance at high levels of consumption which emphasises a balanced feeding ratio rather than unspecific addition (Ospina-Rojas et al., 2020).

For the nutrition of broilers, it is now proposed to set Valine, in particular, as a nutrient with a low limit (Wang et al. 2020). Goo et al. Valine: The neglected branched-chain amino acid in broiler requirements: (2024) Similarly observed a similar relative severity for valine deficiency compared with isoleucine regarding its effect on growth performance indications and who conclude that these findings could indicate that the focus of BCAA requirements of broilers should be more on valine. Kidd and Ragland (2021) also indicated that too many Cu complexes disturb the BCAA-to-lysine ratios thus enhancing the growth performance of broilers from 22 to 35 days. This indicates that BCAAs per se but also BCAA-associated interactions are strong predictors of feed efficiency and BWG.

Meat Yield and Carcass Traits

In addition to the growth performance, BCAA are essential for carcass trait like breast muscle weight [8]. Kriseldi et al. As stated by murder et al (2022), surplus consumption of leucine can also reduce the high breast yield-enhancing effect of high valine and isoleucine in female broilers. This also means that supplementation should be needed to upgrade carcass characteristics without affecting general growth from balanced base diets.

Other studies reported that the animal body composition was responsive to the amounts of these amino acids input to the organism (Kidd & Ragland, 2021), when examining interactive effects which examine the interactive effects of the ratios of leucine, isoleucine and valine. In contrast to studies utilizing commercial BCAA blends with variable levels of crude protein, some studies have observed no positive effect in the absence of precise manipulation of the respective amino acids (Kop-Bozbay et al., 2020; Maynard et al., 2022). Such misalignment suggests the need for practical BCAAs use in terms of their AA relationships instead of only their crude protein contents.

Egg laying and egg quality traits of laying hens

Dietary valine improves eggshell quality and ovalbumin content of eggs and egg production in laying hens in the late phase of peak egg production Jian et al. Valine dietary content between 0.74–0.79% had also indicated that it could have a positive impact on egg quality and immune function. Accordingly, the increased availability of valine improved the absorption of amino acids and the expression of intestinal peptide transporters (its activity, however, was inhibited by overdose) (Jian et al., 2021). Additionally, the BCAA ratio studies suggested that it could preserve egg production and lower nitrogen excretion with low protein diets through the balancing of leucine, isoleucine and valine (Goo et al., 2024). Meaning an functional BCAA blend would help in everyday purpose or pleasures of the green lifestyle by preventing protein overfeeding.

Role of BCAAs in Poultry Health

Effects on Immune System Function

BCAAs regulate both innate and adaptive immunity in chicks fed BCAAs. According to Kim et al. Adequate availability is necessary for immune [...] (2022), lymphoid organ maturation, and antibody production. According to Liu et al. The present results are in line with Agostini et al. (2016) in which optimum level of BCAA supplementation improved immune modulators in challenged birds. Supplementing MP diets with BCAA and arginine to enhance the immune responses, and to counteract coccidian infection-induced damage (2023) in broilers. Also partly assisting with bone mineral retention due to further systemic effects of dietary modulation of valine and isoleucine in necrotic enteritis challenged broilers, the authors indicated that the systemic effects of gut modulating amino acids may not be restricted to gut health (Goo et al., 2025). Additionally, in cell-mediated immunity (Wilkinson et al., 1985), a deficiency in BCAA was also found to decrease spleen and thymus weights and immune re-ponses (Konashi et al., 2000), indicating that the immune organs are densely located with BCAA.

Effects on Gut Microbiota and Gastrointestinal Health

In poultry, BCAAs affect the gut barrier, gut microbiota and microbiome. Goo et al. impact in bacterial community[7] Furthermore, valine scarcity (g) has also a negative effect assigned to Accordingly, Khalilzadeh et al. Indeed, low-protein dietary supplementation with BCAA can promote villus:crypt ratios and increased expression of intestinal IGF-1 gene associated with examples of absorptive capacity and tissue health (2025). Additionally, Kim et al. The data compiled by Plaza-Díaz et al. Although BCAA supplementation is helpful mucosa integrity and microbiota diversity [2] thus leaving targeted mechanistic research is limited [3].

This indicates a protective effect against heat and oxidative stress.

A major obstacle for poultry health and productivity, BCAAs can play a role in the alleviation of heat and oxidative stress-induced detrimental effects. Han et al. L-leucine-enhanced adaptation of broiler chicks to heat stress through regulation of the rectal temperature and amino acid metabolism related genes during heat stress in the in ovo dietary supplementation of heat-stressed broiler chicks (2020). Similarly, Yehia et al. Moreover, Liu et al. In heat-stressed broilers, feeding of BCAAs (plus sulfur amino acids) in the in ovo enhanced antioxidative status

and decreased oxidative damages (2024). As well, Kim et al. overall review BCAAs could act as a stress mitigator by counteracting stress-induced immune dysregulation and oxidative damage, thus improving resilience and health when animals are exposed to adverse environmental circumstances (2022).

Role of BCAAs in Poultry Health

Effects on Immune System Function

Amino acids are the building blocks of protein and nutrition, function as precursors or intermediate compounds in several biosynthetic pathways critical for health, particularly poultry immune responses (Teixeira et al., 2016). Conceptually, BCAAs have a dual function in this respect as an 1) anabolic substrate for the production of proteins within immune tissues and 2) metabolic regulator for immune pathway expression. For instance, leucine activates mTOR pathway which is crucial for lymphocyte proliferation, and cytokine production (Kim et al., 2022).

It has been shown that BCAAenriched ACL Insufli decreases lymphoid organ development (Konashi et al., 2000), antibody titer (Sumandi et al., 1999), and T Lymphocyte activity. Conversely, supplementation enhances immune resilience. Liu et al. The improvements in secretory intestinal IgA expression, increased intestinal villus height and augmented systemic immunological indices that were observed in Eimeria-infected broilers treated with BCAAs plus arginine and fed low-protein diets were demonstrated by (2023).

Similarly, Jian et al. Introduction VLC-AD is during peak egg production for optimal performance valine Gly at 1 g FPA and Imduv (FPA ∗A, g/FBW) VLC-AD (VIP Nitrogen im puting has shown that during peak egg production, a diet [Gly, 2001:2 031] has significantly higher valine supplementation higher valine given in the protein sol. + 1 g FPA (Guan et al. Collectively, these results identify BCAAs at the level of the structural amino acids as novel poultry immune modulators and disease resistance factors, and as potential adjuvant/vaccine response modulators for the next generation.

Influence on Gut Microbiome and Resistance

Pathological therapeutic indications are also given in numerous individual cases with regard to chemical toxicinoses and trauma of the digestive system, the organ of digestion and immunity. Ideal proportions of BCAA likely improve intestine structures and are advantageous to higher performance of villus height and mucosal surface area, lower crypt depth, and higher feed digestibility and absorption efficiency (Goo et al., 2024).

Khalilzadeh et al., found that the administration doses of valine, leucine, and isoleucine elevated the villus height (VH) and up-regulated the gene expression of IGF-1 in jejunum region which suggested the potential anabolic effects on the development of the intestine (Monin & Sellier 1985; Vargas et al. Besides morphology, BCAAs also impact the metabolic activity of the gut microbiota in the ileum. Jian et al. discovered that overall, the cecum microbiota profile affected by the dietary profile of valine was significantly altered and correlated with SCFA production patterns benefiting gut health or systemic immunity. Liu et al. Furthermore, the cecal fermentation profile was beneficial in BCAA-supplemented broilers for butyrate concentration which was high and conserved compared with the other SCFA (Hossain et al. The underlying benefits of BCAAs are not only nutritional and direct but also include microbial ecology and intestinal integrity regulation, both essential for growth and disease resistance in conditions that are if not favour able in intensive poultry systems.

Conclusion

Finally, branched-chain amino acids (BCAA): leucine, isoleucine, and valine appear to have numerous effects in avian nutrition. Besides their classical roles in protein synthesis and growth, BCAAs are also metabolite signals to immune system,gut barrier function, or birds under heat or

oxidative stress. Excessive prosurvival response or a low dose could dampen pro-survival effect which is a metabolically programmed quin. With zero–disease footprint poultry production as the target, more research should be directed towards precision feeding, alternative feeding systems and genetic selection to enhance BCAA utilization.

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