Sources, Metabolic Pathways and Applications of Tryptophan in Poultry Production (Postprint)

Authors: Jing Hansong, Xu Miao, Yang Guiqin

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Abstract

Tryptophan is one of the essential amino acids in animals and the third limiting amino acid in poultry, playing a crucial role in poultry growth, development, and metabolism. This review summarizes the sources, metabolic pathways, and metabolites of tryptophan, poultry tryptophan requirements, and research advances in the application of tryptophan in poultry production.

Full Text

Sources, Metabolic Pathways and Application of Tryptophan in Poultry Production

JING Hansong[1], XU Miao[2], YANG Guiqin[3]*

College of Animal Husbandry and Veterinary Medicine, Shenyang Agricultural University, Shenyang 110866, China
*Corresponding author, professor, E-mail: guiqiny@126.com

Abstract

Tryptophan is one of the essential amino acids in animals and the third limiting amino acid in poultry, playing a crucial role in the growth, development and metabolism of poultry. This review summarizes the research progress on the sources, metabolic pathways, metabolites, requirements and application of tryptophan in poultry production.

Key words: tryptophan; source; metabolic pathway; requirement; poultry

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The chemical name of tryptophan is -amino- -indolepropionic acid, with the molecular formula C H N O and a relative molecular mass of 204.33. It appears as white or slightly yellow crystals with a distinctive odor. Tryptophan contains 13.7% nitrogen and has a metabolic energy value of 23.9 MJ/kg for poultry. Tryptophan exists in three isomeric forms: L-type, D-type and DL-type. Naturally occurring tryptophan is exclusively L-tryptophan, while synthetic tryptophan includes both L-tryptophan and DL-tryptophan. Since L-tryptophan exists in the form absorbed by the small intestine, its digestibility is 100% [1]. In vivo, DL-tryptophan can be converted into L-tryptophan (80% in pigs, 50–60% in chickens) and then metabolized to synthesize various physiologically active substances [2]. This review summarizes the sources and metabolic pathways of tryptophan, its effects on poultry production performance, nutrient metabolism and immune function, and compiles recent research progress on tryptophan and digestible tryptophan requirements in poultry, providing a reference for the rational utilization of tryptophan in poultry production and scientific research.

1.1 Sources of Tryptophan

Tryptophan serves multiple physiological functions, but poultry cannot synthesize it endogenously or can only synthesize it at extremely low levels insufficient to meet their needs, making dietary supplementation necessary. High-protein feedstuffs such as fish meal, soybean meal and peanuts are rich in tryptophan. Since corn contains low levels of tryptophan (0.07%), corn-soybean meal-based diets are often deficient in tryptophan, which is therefore considered the third limiting amino acid in poultry after methionine and lysine [3]. Poultry exhibit substantial differences in tryptophan digestibility from various sources, making formulation based on digestible tryptophan more accurate for diet preparation. Table 1 lists the tryptophan and digestible tryptophan contents in major protein feedstuffs for poultry [4–5].

In addition to natural feed ingredients, tryptophan is primarily produced through microbial fermentation, protein hydrolysis, and chemical synthesis combined with enzymatic racemization, with microbial fermentation having become the dominant practical production method [2]. In the feed industry, tryptophan is mainly used as an additive.

Digestible tryptophan content = tryptophan content × ileal amino acid digestibility of chicken.

1.2 Metabolic Pathways and Metabolites of Tryptophan

Tryptophan is metabolized in poultry through three main pathways: (1) The 5-hydroxytryptamine (5-HT) pathway, where tryptophan is converted to 5-hydroxytryptophan by tryptophan hydroxylase and then decarboxylated to form 5-HT [6]. (2) The kynurenine (KYN) pathway, where tryptophan is converted to KYN by indoleamine-2,3-dioxygenase or tryptophan-2,3-dioxygenase, and through multiple enzymatic reactions generates quinolinic acid, picolinic acid derivatives, nicotinamide adenine dinucleotide (NAD) and NAD phosphate (NADP) [7]. (3) The indole and skatole pathway, where L-tryptophan undergoes deamination and decarboxylation by various microorganisms to produce indole, indoleacetic acid, indolepyruvic acid and skatole [8]. The major metabolic pathways of tryptophan in poultry are illustrated in Figure 1 [Figure 1: see original paper].

[Figure 1: see original paper]

The main metabolites of tryptophan include 5-HT, KYN, melatonin (MT), NAD and NADP [6–7], indole and skatole [8]. 5-HT is a potent vasoconstrictor and smooth muscle contraction stimulant that also acts on the central nervous system to regulate feeding behavior in animals. Research has shown that altering hypothalamic 5-HT concentration can regulate feed intake and energy metabolism in ducks [9]. 5-HT exerts its effects by inhibiting gastrointestinal regulatory peptides and synergizing with other appetite-suppressing factors [10]. Viljoen et al. [11] demonstrated that KYN is converted to kynurenic acid in animals and oxidized to nicotinic acid, serving as a precursor for NAD and NADP synthesis. During severe inflammatory responses, vascular endothelial cells produce large amounts of KYN, which has potent vasodilatory and blood pressure-lowering effects [12]. MT is an indole hormone synthesized and secreted by pineal gland cells from L-tryptophan through a series of enzymatic reactions, regulated via both sympathetic nerves and the hypothalamic-pituitary-adrenal axis. It plays important regulatory roles in controlling circadian rhythms, sex hormone secretion and immune function [13]. Indole is the primary metabolite of L-tryptophan, formed when indolepyruvic acid removes -ketoglutaric acid. With enzymatic participation, the C–C bond of tryptophan breaks to produce indole, indolepyruvic acid and ammonia. Indolepyruvic acid is decarboxylated by various microorganisms to form indoleacetic acid, which is the main precursor of skatole. Skatole is formed when indoleacetic acid loses its carbonyl group under the action of specific microorganisms and an unidentified decarboxylase [14]. Indole and skatole have strong fecal odors with strong diffusibility and persistence, making them among the most malodorous compounds in pig and poultry manure [15].

2.1 Effects of Tryptophan on Poultry Growth Performance

Wang et al. [16] reported that dietary tryptophan level showed a significant quadratic relationship with average daily feed intake (ADFI) and average daily gain (ADG) in 1–21 day-old broilers, with optimal tryptophan requirements of 0.248% and 0.234% for male and female broilers, respectively. When dietary tryptophan reached 0.202%, ADFI in 1–21 day-old Peking ducks was significantly increased [17]. As dietary tryptophan levels increased, ADFI in 1–28 day-old Sichuan white geese first increased and then decreased, reaching maximum at 0.190% tryptophan [18]. These findings demonstrate that appropriate L-tryptophan supplementation can increase feed intake in poultry, while excessive supplementation inhibits feed intake. According to Birkl et al. [19], tryptophan deficiency reduces plasma tryptophan levels, affecting serotonin synthesis and consequently decreasing feed intake, even leading to feather-pecking behavior.

Beyond affecting feed intake, both deficiency and excess of dietary tryptophan can reduce ADG in broilers [20]. Opoola et al. [21] found that dietary tryptophan supplementation improved ADG and ADFI in 1-28 day-old and 33–56 day-old broilers, with optimal dietary tryptophan levels of 0.24% and 0.21%, respectively. The apparent ileal digestible tryptophan requirements for maximum ADG and minimum feed-to-gain ratio in 1-21 day-old male broilers were 0.174% and 0.186%, respectively [22]. Ma et al. [23] observed that adding 0.18% tryptophan to the basal diet increased the body weight of newly hatched yellow-feathered broiler chicks by 3.99%. The mechanisms through which tryptophan affects poultry growth include: (1) as a nutrient, tryptophan directly participates in protein synthesis, promoting growth; and (2) the tryptophan metabolite 5-HT influences growth and development by affecting the synthesis and secretion of thyroid hormones [triiodothyronine (T), thyroxine (T)] and growth hormone [24].

2.2 Effects of Tryptophan on Poultry Egg Production Performance

Yuan et al. [25] demonstrated that appropriate dietary tryptophan levels promoted gonadotropin release and improved protein utilization and laying performance in Lohmann layers, with an optimal tryptophan level of 0.20% in corn-soybean meal diets. Huang et al. [26] found that adding 0.04% tryptophan significantly increased egg weight in 33-week-old dwarf layers and brown-shell layers, but egg weight decreased significantly when tryptophan reached 0.06%. Hou et al. [27] reported that adding 0.20% tryptophan to low-protein (15%) diets improved laying rate and reduced feed-to-egg ratio in 35–40 week-old Hy-Line gray layers. He [28] showed that supplementing 0.06% and 0.08% L-tryptophan to corn-soybean meal diets containing 0.15% L-tryptophan significantly improved laying rate in 29–40 week-old XinYang green-shell layers. However, tryptophan effects are less pronounced in ducks and geese. Zhang et al. [29] reported that dietary tryptophan levels of 0.12–0.32% had no significant effects on laying rate, egg weight or daily egg mass in Shanma laying ducks (120–260 days), though curve fitting based on laying rate and feed-to-egg ratio indicated a minimum requirement of 0.20% during peak production. Yu et al. [30] found that adding 0.03% tryptophan to the basal diet increased egg weight and laying rate in Changbai breeding geese, though differences were not significant compared with the control group.

Overall, substantial research has been conducted on tryptophan's effects on poultry production performance, particularly in broilers and laying hens, yielding relatively consistent results. However, further research is needed on tryptophan' s effects and optimal supplementation levels in duck and goose production.

2.3 Tryptophan Requirements of Poultry

Determining optimal tryptophan requirements depends on poultry breed, growth stage, sex, environmental temperature, stocking density, lighting and dietary amino acid balance. During inflammatory responses, tryptophan catabolism increases, raising the requirement [31]. Recent research on tryptophan requirements for major poultry species in corn-soybean meal-based diets is summarized in Table 2 . As shown in Table 2, optimal tryptophan requirements are 0.21–0.25% for broilers, 0.19–0.22% for laying hens, 0.20–0.30% for laying ducks and 0.22% for geese. Optimal digestible tryptophan requirements are 0.17–0.19% for laying hens and 0.11–0.23% for broilers.

3.1 Effects of Tryptophan on Poultry Protein Metabolism

Tryptophan is one of 11 essential amino acids in poultry, participating in protein synthesis and metabolism. Its source, level and balance with other amino acids directly affect protein synthesis rate and nitrogen excretion. Hou et al. [27] demonstrated that adding 0.20% tryptophan to low-protein (15%) diets effectively reduced nitrogen excretion in Hy-Line gray layers. At 0.19% dietary tryptophan, nitrogen retention was significantly improved in 28-week-old XinYang green-shell layers [28]. Tryptophan deficiency reduced body protein deposition in yellow-feathered broiler cocks and hens, while crystalline tryptophan supplementation increased protein deposition by 21.0–31.8% in cocks and 5.4–27.9% in hens during 1–21 days [43]. Tryptophan supplementation to low-tryptophan diets also improved protein utilization in Yangzhou geese [44].

Since poultry lack carbamoyl phosphate synthetase in mitochondria, they cannot obtain ornithine and carbamoyl phosphate, limiting citrulline synthesis and preventing a functional urea cycle [45]. Consequently, the end product of protein metabolism in poultry is uric acid rather than urea. Liu [46] found that increasing dietary digestible tryptophan from 0.17% to 0.19% elevated blood uric acid content in broilers, though blood uric acid decreased with reduced dietary protein and increased digestible tryptophan levels. Rao [47] reported that compared with the control group (0.17% tryptophan, 15% crude protein), 0.19% dietary tryptophan significantly increased serum total protein and albumin while decreasing serum urea nitrogen and uric acid in laying hens. Wang [39] showed that adding 0.04–0.06% tryptophan to the basal diet significantly increased serum total protein and reduced serum urea nitrogen in Xichangma ducks. These results indicate that appropriate tryptophan levels improve dietary amino acid balance, enhance amino acid utilization, reduce nucleic acid catabolism and promote protein deposition in poultry.

3.2 Effects of Tryptophan on Poultry Lipid Metabolism

Dietary tryptophan level affects not only lipid metabolism but also plasma triglyceride and cholesterol concentrations [47]. Zhou et al. [48] demonstrated that dietary L-tryptophan supplementation significantly reduced abdominal and liver fat percentages, promoting lipid metabolism in late-stage laying hens, with 0.04% supplementation showing optimal effects. Davoudi et al. [49] reported that tryptophan increased activities of lactate dehydrogenase, alanine aminotransferase and alkaline phosphatase in liver, thereby reducing blood triglyceride levels in broilers. Dietary tryptophan supplementation at 0.06–0.09% significantly reduced serum triglyceride content in 1–3 week-old broilers [50]. Serum triglyceride and total cholesterol levels were lowest in laying hens at 0.24% tryptophan supplementation [34]. Adding 0.04% tryptophan to the basal diet significantly reduced serum triglyceride and cholesterol levels and decreased fat synthesis and deposition in Xichangma ducks [39]. These findings demonstrate that beyond protein synthesis, tryptophan participates in lipid synthesis and cholesterol metabolism regulation by influencing hepatic fatty acid metabolism, thereby reducing fat synthesis and deposition in poultry.

3.3 Effects of Tryptophan on Poultry Immune Function

Harden et al. [51] reported that dietary tryptophan deficiency suppresses immune function, significantly increasing morbidity and mortality, which are alleviated by tryptophan supplementation. Wang [50] found that dietary tryptophan supplementation significantly increased serum immunoglobulin G (IgG) and IgA contents in 1–3 week-old broilers, peaking at 0.06% supplementation before declining. Tryptophan supplementation also significantly increased thymus, spleen and bursa indices in ducks [52]. Wei [53] demonstrated that tryptophan significantly increased serum IgG and IgM contents in Yangzhou geese. Dietary L-tryptophan supplementation significantly increased serum interferon- , interferon- and IgG contents in broilers, enhancing humoral and cellular immune responses to infectious bursal disease [54]. These results indicate that as a limiting amino acid related to immune proteins, tryptophan affects both cellular immune regulation and directly participates in humoral immunity.

4 Conclusion

In summary, tryptophan is the third limiting amino acid in poultry. Appropriate dietary tryptophan levels can promote feed intake, improve production performance, enhance nutrient metabolism and boost immunity. However, research on the effects of tryptophan sources and levels on product quality and malodorous compound concentrations in excreta remains limited. The potential interactive effects between dietary tryptophan and carbohydrates on production performance, nitrogen excretion and metabolic mechanisms require further investigation. In-depth understanding of tryptophan' s nutritional and physiological functions at the cellular and molecular levels will have important theoretical significance. As tryptophan synthesis technology matures and production costs decrease, along with continued functional research, tryptophan will play an increasingly important role in poultry production.

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