Veterinary & Life Science Innovations

Veterinary & Life Science Innovations 2025;3(1):21-24

Review Article

The Role of Tryptophan Supplementation in Enhancing Gut Health, Antioxidant Activity, and Reproductive Performance in Broiler and Broiler Breeder Chickens

Henri Eko PRASETYO [1]

[1] Animal Nutritionist & Business Development, PT. Dinamika Megatama Citra (DMC) Indonesia Company, Jl. Raya Mojosari Ngoro Km. 3, Pungging, Dusun Pungging, Pungging, Kec. Pungging, Kabupaten Mojokerto, JawaTimur61384

(*) Corresponding author:

Henri Eko PRASETYO

E-mail: henriekoprasetyo@gmail.com

Received: 15-08-2025 | Accepted: 30-09-2025 | Published: 20-12-2025

Tryptophan (Trp) is an essential amino acid in broiler nutrition with roles extending beyond protein synthesis. As a precursor for serotonin, melatonin, and niacin, Trp supports gut health by enhancing motility, villus morphology, tight junction integrity, and promoting beneficial microbiota while suppressing pathogens. Its conversion to melatonin improves antioxidant capacity by increasing superoxide dismutase, catalase, and glutathione peroxidase activities, reducing oxidative damage in muscle, and improving meat quality by lowering drip loss and the incidence of pale, soft, and exudative (PSE) meat. Trp also mitigates heat stress by modulating the hypothalamic–pituitary–adrenal axis, reducing circulating stress hormones, and decreasing heat shock protein expression. Through the kynurenine pathway, Trp metabolism enhances immune function by supporting lymphocyte activity, cytokine production, and maintaining intestinal IgA levels even under toxin exposure such as ochratoxin A. However, excessive supplementation may provoke local inflammatory responses, underscoring the need for precise dietary balance. These mechanisms highlight Trp's multifaceted role as both an essential nutrient and a functional feed additive that can improve growth performance, health, and welfare in modern broiler production systems.

Keywords: Antioxidant, Broiler, Poultry nutrition, Tryptophan

INTRODUCTION

Over the past several years, the growth performance of modern commercial broiler strains has continued to improve due to advances in genetic selection (Choi et al., 2023). From 1957 to 2005, broiler growth increased by over 400%, with a 50% reduction in feed conversion ratio (Zuidhof et al., 2014). This translates to a 3.30% annual increase in 42-day live body weight and a 2.55% yearly decrease in feed conversion ratio. Such improvements are likely to affect the maintenance and growth requirements for amino acids.

Among these, Trp stands out as an amino acid with a range of beneficial effects and a wide variety of metabolic activities pada ayam broiler (Corzo, 2012). Because its concentration in organisms is among the lowest of all amino acids, it can easily play a rate-limiting role in protein synthesis.

Beyond its role in protein synthesis, tryptophan serves as a precursor for serotonin, melatonin, and niacin, influencing numerous physiological processes (Davidson et al., 2022). Recent studies have highlighted Trp's potential to modulate gut integrity, reduce oxidative stress, and support reproductive functions in broilers (Ouyang et al., 2022). This article reviews the current understanding of Trp’s roles in broiler, with an emphasis on its impact on performance, antioxidant capacity, stress responses, meat quality, and immune response.

DATA SOURCES

A comprehensive literature search was conducted using databases such as PubMed, Scopus, and Web of Science, focusing on studies published between 2010 and 2025. Keywords included "tryptophan," "broiler," "broiler breeder," "antioxidant," "gut health," and "reproduction."

TRYPTOPHAN SOURCES

Tryptophan is an essential amino acid naturally present in various plant-based food sources, particularly legumes and seeds such as cashews, walnuts, peanuts, almonds, sesame seeds, pumpkin seeds, sunflower seeds, and soybeans (Strasser et al., 2016; Nayak et al., 2022). In poultry nutrition, Trp is classified as the third limiting amino acid after methionine and lysine (Galili et al., 2016). Although commercial cereal grains such as corn and wheat are frequently used as primary energy sources in broiler diets, their Trp content is relatively low (Bolarinwa and Adeola, 2012; Barua et al., 2021; Khalil et al., 2021). To meet the birds’ nutritional requirements for this amino acid, supplementation with synthetic Trp is a common practice in feed formulation. Nevertheless, the use of synthetic Trp often faces economic challenges due to its higher cost compared to conventional feed ingredients (Friedman, 2018).

REQUIREMENTS AND OPTIMAL DOSAGE OF TRYPTOPHAN IN BROILER CHICKENS

Tryptophan is an essential amino acid that plays a critical role in broiler feed formulation. Trp deficiency has wide-ranging impacts, not only reducing growth performance and feed efficiency but also impairing protein deposition, worsening feed conversion, and lowering carcass yield and reproductive quality (Fouad et al., 2021). Layers and broiler breeders fed Trp-deficient diets have shown reduced egg production, egg weight, fertility, and hatchability (Cardoso et al., 2014; Jiang et al., 2018). In broilers, these negative effects manifest as stunted growth and reduced carcass quality (Pan et al., 2013; Wang et al., 2016).

The requirement for Trp depends significantly on the growth phase and sex of the birds. During the starter phase, the optimal level is estimated at approximately 0.18% (Javed, 2020), rising to around 0.198% during the subsequent grower phase, and declining again to approximately 0.16% between 42 and 56 days of age (Lisnahan and Nahak, 2020). Interestingly, several studies have reported that increasing dietary Trp levels to 0.23–0.30% can enhance feed intake, average daily gain, and feed conversion efficiency (Cortamira et al., 1991; Dong and Zou, 2017).

Apart from the dose of Trp that needs to be considered, achieving a proper balance between Trp and other amino acids such as lysine is crucial for supporting optimal growth. For example, research on Ross 208 broilers aged 20–40 days found that a Trp-to-lysine ratio of 19% produced the best outcomes in terms of body weight gain and feed efficiency (Wecke and Liebert, 2013). However, a range of 17–19% is generally considered adequate, with even lower ratios around 16.6% still supporting satisfactory growth performance (Corzo, 2012). On the other hand, not all studies have shown consistent results. Some research has found that increasing Trp levels (0.5-0.24%) in the diet does not always significantly affect carcass parameters such as breast, thigh, and wing weights (Duarte et al., 2013; Mund et al., 2020). This variability appears to be influenced by multiple factors, including diet composition, the birds' physiological status, and nutrient interactions. Even when dietary Trp levels were increased to 1.5–3 times the recommended requirement, meaningful improvements in performance were not always observed (Goo et al., 2019; Wang et al., 2014). Nevertheless, some reports indicate that performance improvements can be achieved when supplementation is targeted during the starter phase, particularly at doses 0.5–2.5 times the requirement (Emadi et al., 2011; Mund et al., 2019).

EFFECTS OF TRYPTOPHAN ON BROILER PERFORMANCE

Tryptophan is an essential amino acid that plays a central role in various physiological processes in broiler chickens, particularly in supporting growth, metabolic efficiency, and stress resilience (Fouad et al., 2021). Optimal dietary availability of Trp has been linked to improved egg production, enhanced egg quality, and higher chick viability, especially in broiler breeders (Jiang et al., 2018).

Increased body weight and feed conversion ratio (FCR) were also recorded in broilers with 0.3% and 0.5% Trp supplementation (Mund et al., 2020). These positive effects are largely mediated through Trp's ability to stimulate the secretion of growth-related hormones such as insulin and insulin-like growth factor I (IGF-I), thereby supporting anabolic processes and tissue growth (Dukes et al., 2015). Trp also activates the mTOR signaling pathway and enhances the expression of amino acid transporters such as SLC6A19 and SLC6A14, which facilitate protein synthesis and muscle accretion (Wang et al., 2015; Timosenko et al., 2016).

Tryptophan also plays a crucial role in maintaining gut health and promoting physiological performance in poultry through serotonin biosynthesis (Javed, 2020). Serotonin, synthesized from Trp in the gastrointestinal tract, is known to enhance intestinal motility and secretion, while Trp-derived metabolites such as indole derivatives contribute to mucosal integrity and regulate local immune responses (Wang et al., 2015). These effects improve intestinal morphology, evidenced by increased villus height, higher villus-to-crypt ratios, and upregulation of tight junction protein expression, all of which reflect enhanced nutrient absorption capacity and epithelial barrier function. This benefit has also been observed under low-protein diet conditions, where Trp supplementation mitigated growth performance losses and promoted feed intake (Sato et al., 2021).

Regarding the gut microbiota, Trp exerts important influences by increasing the abundance of beneficial bacteria such as *Faecalibacterium, Lachnospiraceae_NC2004_*, and *Ruminococcus_torques_group* while suppressing pathogenic species in Arbor Acres with 0.2% Trp supplementation in feed, thereby supporting gastrointestinal homeostasis (Ma et al., 2024). The maintenance of microbial balance and the inhibition of pathogens such as *Salmonella* and *Shigella* are partly attributed to the microbial metabolism of Trp into indole and its derivatives (Gao et al., 2018).

IMPACT OF TRYPTOPHAN ON ANTIOXIDANT CAPACITY, STRESS RESPONSES, MEAT QUALITY IN BROILERS

Dietary Trp supplementation has been shown to confer antioxidant benefits in broiler chickens. Inclusion of 0.18% Trp in the diet of Arbor Acres broilers has been reported to improve antioxidant capacity and stress resilience by increasing the activities of superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GSH-Px), total antioxidant capacity (T-AOC), and related mRNA expression levels, while reducing malondialdehyde (MDA) concentrations (Ouyang et al., 2022). This protective effect is largely mediated by the metabolic conversion of Trp to melatonin, a potent free radical scavenger (Tan et al., 2015). Melatonin is known to increase the activities of antioxidant enzymes such as superoxide dismutase SOD, GSH-Px, CAT, and T-AOC, thereby reducing oxidative stress across various tissues (Lee, 2025).

Beyond melatonin, Trp metabolism also yields other bioactive compounds with antioxidant properties, including 5-hydroxytryptophan and 3-hydroxykynurenine, which help regulate reactive oxygen species (ROS) production and maintain cellular redox balance (Christen et al., 1990; Huether et al., 1992; Liu et al., 2015). The indole structure of Trp itself can stabilize free radicals through resonance, allowing it to act as a direct antioxidant (Linh et al., 2021).

At the molecular level, Trp has been shown to activate the antioxidant response element (ARE) pathway, promoting the expression of enzymes such as paraoxonase-1 (PON1), which plays a key role in protecting lipoproteins from lipid oxidation (De la Iglesia et al., 2014; Wang et al., 2014). However, not all studies have reported consistent results. For instance, Ayazi et al. (2014) found that Trp supplementation did not significantly affect MDA levels or T-AOC in heat-stressed broilers. Such discrepancies may be influenced by factors including dosage, bird age, stress duration, or differences between enzyme activity and gene expression.

Beyond its antioxidant effects, Trp is also known to reduce stress levels in broiler chickens. Conversely, Trp deficiency has been shown to disrupt multiple physiological functions and increase vulnerability to stress (Birkl et al., 2017). Chronic heat stress can profoundly affect broiler physiology and behavior, reducing the expression of digestive enzymes and nutrient transporter genes, thereby impairing digestion and nutrient absorption (Al-Zghoul et al., 2019). Heat stress can also modulate brain monoamine levels and their metabolites, impacting the hypothalamic–pituitary–adrenal (HPA) axis and leading to neuroendocrine, metabolic, behavioral, and immune dysfunction (Calefi et al., 2019).

Tryptophan appears to mitigate heat stress in broilers through three main mechanisms. First, Trp enhances the expression of tryptophan hydroxylase 1 (TPH1), tryptophan hydroxylase 2 (TPH2), and arylalkylamine Nacetyltransferase (AANAT) in the liver and hypothalamus (Liu et al., 2015; Bello et al., 2018). This is especially relevant because heat stress reduces AANAT expression while increasing monoamine oxidase (MAO) activity and serotonin transporter (SERT) expression, disrupting serotonin and melatonin homeostasis (Calefi et al., 2019). Second, Trp modulates the HPA axis by reducing plasma levels of epinephrine (EPI), dopamine (DA), norepinephrine (NA), and corticotropin-releasing hormone (CRH) in heat-stressed broilers (Li et al., 2021; Yue et al., 2017). Third, Trp lowers serum heat shock protein 70 (HSP70) and corticosterone (CORT) levels, indicating improved cellular stress tolerance (Soleimani et al., 2012a, 2012b). Additionally, Trp supplementation has been shown to upregulate the expression of mitochondrial genes such as PGC-1α, Cyt-c, COX1, COX5A, and SIRT1 in the livers of heat-stressed broilers (Liu et al., 2019).

The protective effects of Trp are not limited to biochemical pathways but are also reflected in behavioral outcomes and animal welfare during heat stress. Several studies have reported that Trp supplementation of 2% can reduce aggressive behaviors and feather pecking associated with stress, thereby supporting improved welfare and production performance in broilers (Hierden et al., 2004; Yıldırım et al., 2020; Bai et al., 2017).

Increasing antioxidant status with Trp supplementation also has an impact on reducing oxidative damage in muscle fibers, thereby preserving myofibrillar integrity, lowering protein denaturation, and improving water-holding capacity. Such effects significantly reduce drip loss and shear force, while decreasing the incidence of pale, soft, and exudative PSE meat, particularly in birds exposed to environmental or transportation stress (Bowker and Zhuang, 2015; Emadi et al., 2011; Wang et al., 2014).

Moreover, dietary supplementation with Trp at levels of 0.25–0.27% for three weeks before slaughter has been reported to improve breast meat tenderness and juiciness, likely through stabilization of muscle cell membranes and reduction of intracellular water loss (Wang et al., 2014, 2015). Therefore, Trp functions not only as an essential nutrient but also as a functional agent capable of enhancing meat quality through oxidative protection and modulation of physiological stress.

TRYPTOPHAN EFFECTS ON THE IMMUNE RESPONSE IN BROILERS

Tryptophan deficiency has been associated with reduced immune organ size, impaired antibody production, and elevated corticosterone secretion with immunosuppressive effects (Bai et al., 2017; Mehaisen et al., 2017).

Beyond its role as a neurotransmitter precursor in the central nervous system, Trp also plays an important role in immune system regulation, particularly via the kynurenine metabolic pathway (Li, 2023). The kynurenine pathway of tryptophan metabolism is critical for immune regulation and produces neuroactive metabolites (Badawy, 2017; Schwarcz et al., 2012). This pathway is controlled by enzymes such as tryptophan 2,3-dioxygenase (TDO) and indoleamine 2,3-dioxygenase (IDO), which are regulated by hormones, cytokines, and other factors (Badawy, 2017). The immunomodulatory effects of Trp are also supported by its ability to enhance lymphocyte activity and promote pro-immune cytokine production (Linh et al., 2021).

In relation to its effects on toxicity, Trp at a dose of 100 mg/kg body weight has demonstrated protective potential against toxins such as ochratoxin A (OTA) by mitigating its suppressive effects on intestinal mucosal IgA production in broiler chickens (Ricci et al., 2021). This effect is likely mediated by serotonin, a Trp-derived metabolite, which has been shown to enhance B-lymphocyte proliferation via activation of 5-HT1A receptors and act as an effective antioxidant to counter oxidative stress—one of the main mechanisms of OTA toxicity (Strasser et al., 2016). Moreover, N-acetyl-L-tryptophan (NAT), a Trp derivative, has been shown in vitro to inhibit OTA-induced renal cell damage, including effects on cell proliferation, protein synthesis, and DNA integrity (Argawal et al., 2022). These findings underscore Trp's potential as both an immunoprotective agent and a detoxifier.

However, it is important to note that excessive Trp supplementation of 0.1%, can stimulate the expression of inflammatory markers such as TLR4, TNF-α, and IL-6 in the ileal mucosa (Li et al., 2025), suggesting that an overly activated immune response may also pose a risk of local inflammation. In addition, the effects of Trp on performance can be briefly seen in Table 1.

CONCLUSION

Tryptophan is a vital dietary component in broiler nutrition, exerting its effects through multiple mechanisms. As a serotonin precursor, it enhances gut motility, barrier integrity, and microbiota balance, promoting nutrient absorption and intestinal health. Through melatonin synthesis, Trp strengthens antioxidant defenses by increasing SOD, GSH-Px, and CAT activities, reducing oxidative stress, and improving resilience to heat stress via HPA axis modulation. The kynurenine pathway mediates immunomodulatory effects, supporting lymphocyte function and cytokine production while protecting against mycotoxins. However, excessive supplementation may provoke local inflammatory responses. Balancing Trp inclusion in poultry diets is therefore critical to optimize growth, health, immune competence, and meat quality, underscoring its importance as both a nutrient and functional feed additive.

REFRENCES

1. Al-Zghoul MB, Alliftawi ARS, Saleh KMM, Jaradat ZW. Expression of digestive enzyme and intestinal transporter genes during chronic heat stress in the thermally manipulated broiler chicken. *Poult Sci*. 2019;98(9):4113–4122. doi:10.3382/ps/pez249
2. Agarwal P, Khodlan P, Kalra N, Raisuddin S, Kumar R. In-vitro alleviation of ochratoxin a mediated cytotoxicity using N-acetyl-L-tryptophan glucoside pretreatment. *Life Sci*. 2022;308:120968. doi: 10.1016/j.lfs.2022.120968
3. Ayazi M. Effect of dietary glutamine and vitamin E supplementation on performance, some blood antioxidant indices in broiler chickens under continuous heat stress temperature. *Int J Farm Allied Sci*. 2014;3(12):1303-1310.
4. Badawy AA-B. Kynurenine pathway of tryptophan metabolism: regulatory and functional aspects. *Int J Tryptophan Res*. 2017;10:1–20. doi:10.1177/1178646917691938
5. Bai M, Liu H, Xu K, Oso AO, Wu X, Liu G, Tossou MC, Al-Dhabi NA, Duraipandiyan V, Xi Q, Yin Y. A review of the immunomodulatory role of dietary tryptophan in livestock and poultry. *Amino Acids*. 2017;49(1):67-74. doi:10.1007/s00726-016-2342-3
6. Barua M, Abdollahi MR, Zaefarian F, Wester TJ, Girish CK, Ravindran V. Influence of feed form on the standardised ileal amino acid digestibility of common grains for broiler chickens. *Anim Feed Sci Technol*. 2021;272:114743. doi:10.1016/j.anifeedsci.2020.114743
7. Bello A, Idrus Z, Yong Meng G, Awad EA, Soleimani FA. Gut microbiota and transportation stress response affected by tryptophan supplementation in broiler chickens. *Ital J Anim Sci*. 2018;17(1):107-113. doi:10.1080/1828051X.2017.1340814

8. Birkl P, Kjaer JB, Szkotnicki W, Forsythe P, Harlander-Matauschek A. Acute tryptophan depletion: the first method validation in an avian species (*Gallus gallus domesticus*). *Poult Sci*. 2017;96(9):3021-3025. doi:10.3382/ps/pex089
9. Bolarinwa OA, Adeola O. Energy value of wheat, barley, and wheat dried distillers grains with solubles for broiler chickens determined using the regression method. *Poult Sci*. 2012;91(8):1928-1935. doi:10.3382/ps.2011-02095
10. Bowker B, Zhuang H. Relationship between water-holding capacity and protein denaturation in broiler breast meat. *Poult Sci*. 2015;94(7):1657-1664. doi:10.3382/ps/pev140
11. Calefi AS, Fonseca JGS, Nunes CAQ, Lima APN, Quinteiro-Filho WM, Flório JC, Zager A, Ferreira AJP, Palermo-Neto J. Heat stress modulates brain monoamines and their metabolites production in broiler chickens co-infected with *Clostridium perfringens* type A and *Eimeria spp*. *Vet Sci*. 2019;6(1):4. doi:10.3390/vetsci6010004
12. Cardoso AS, Costa FGP, Vilar da Silva JH, Saraiva EP, Nogueira ET, Santos CS, Ramalho de Lima M, Vieira DVG. Nutritional requirement of digestible tryptophan for white-egg layers of 60 to 76 weeks of age. *J Appl Poult Res*. 2014;23(4):729-734. doi:10.3382/japr.2013-00961
13. Choi J, Kong B, Bowker BC, Zhuang H, Kim WK. Nutritional strategies to improve meat quality and composition in the challenging conditions of broiler production: a review. *Animals (Basel)*. 2023;13(8):1386. doi:10.3390/ani13081386
14. Christen S, Peterhans E, Stocker R. Antioxidant activities of some tryptophan metabolites: possible implication for inflammatory diseases. *Proc Natl Acad Sci USA*. 1990;87(7):2506-2510. doi:10.1073/pnas.87.7.2506
15. Corzo A. Determination of the arginine, tryptophan, and glycine ideal-protein ratios in high-yield broiler chicks. *J Appl Poult Res*. 2012;21(1):79-87. doi:10.3382/japr.2011-00362
16. Cortamira N, Seve B, Lebreton Y, Ganier P. Effect of dietary tryptophan on muscle, liver and whole-body protein synthesis in weaned piglets: relationship to plasma insulin. *Br J Nutr*. 1991;66(3):423-435. doi:10.1079/BJN19910045
17. Davidson M, Rashidi N, Nurgali K, Apostolopoulos V. The role of tryptophan metabolites in neuropsychiatric disorders. *Int J Mol Sci*. 2022;23(17):9968. doi:10.3390/ijms23179968
18. De la Iglesia R, Mansego ML, Sanchez-Muniz FJ, Zulet MA, Martinez JA. Arylesterase activity is associated with antioxidant intake and paraoxonase-1 (PON1) gene methylation in metabolic syndrome patients following an energy restricted diet. *EXCLI J*. 2014;13:416-426.
19. Dong X, Zou X. Effects of excess dietary tryptophan on laying performance, antioxidant capacity and immune function of laying hens. In: Amino Acid—New Insights and Roles in Plant and Animal. InTech; 2017.
20. Duarte KF, Otto MJ, Rosemeire SF, Siqueira JCD, Puzotti MM, Garcia EA, Molino ADB, Laurentiz ACD. Digestible tryptophan requirements for broilers from 22 to 42 days old. *R Bras Zootec*. 2013;42(10):728-733. doi:10.1590/S1516-35982013001000004
21. Dukes A, Davis C, El Refaey M, Upadhyay S, Mork S, Arounleut P, Johnson MH, Hill WD, Isales CM, Hamrick MW. The aromatic amino acid tryptophan stimulates skeletal muscle IGF1/p70s6k/mTor signaling in vivo and the expression of myogenic genes in vitro. *Nutrition*. 2015;31:1018–1024. doi:10.1016/j.nut.2015.02.011
22. Emadi M, Jahanshiri F, Kaveh K, Hair-Bejo M, Ideris A, Alimon R. Tryptophan stimulates immune response in broiler chickens challenged with infectious bursal disease vaccine. J Anim Vet Adv. 2010a;9:610-616.
23. Emadi M, Kaveh K, Johnshiri F. Dietary tryptophan effects on growth performance and blood parameter levels in broiler chicks. J Anim Vet Adv. 2010b;9:700-704.

24. Emadi M, Jahanshiri F, Kaveh K, Hair-Bejo M, Ideris A, Alimon AR. Nutrition and immunity: The effects of the combination of arginine and tryptophan on growth performance, serum parameters and immune response in broiler chickens challenged with infectious bursal disease vaccine. *Avian Pathol*. 2011;40(1):63-72. doi:10.1080/03079457.2010.539031
25. Fatemi M, Toghyani M. Effect of tryptophan supplementation in protein deficient diets on performance, gut development and immune responses in broiler chickens. Iran J Appl Anim Sci. 2018;8(1):101-108.
26. Fouad AM, El-Senousey HK, Ruan D, Wang S, Xia W, Zheng C. Tryptophan in poultry nutrition: Impacts and mechanisms of action. *J Anim Physiol Anim Nutr (Berl)*. 2021;105(5):1146-1153. doi:10.1111/jpn.13515
27. Galili G, Amir R, Fernie AR. The regulation of essential amino acid synthesis and accumulation in plants. *Annu Rev Plant Biol*. 2016;67:153-78. doi:10.1146/annurev-arplant-043015-112213
28. Gao J, Xu K, Liu H, Liu G, Bai M, Peng C, Li T, Yin Y. Impact of the gut microbiota on intestinal immunity mediated by tryptophan metabolism. *Front Cell Infect Microbiol*. 2018;8:13. doi:10.3389/fcimb.2018.00013
29. Goo D, Kim JH, Park GH, Delos Reyes JB, Kil DY. Effect of stocking density and dietary tryptophan on growth performance and intestinal barrier function in broiler chickens. *Poult Sci*. 2019;98(10):4504-4508. doi:10.3382/ps/pez284
30. Huether G, Poeggeler B, Reimer A, George A. Effect of tryptophan administration on circulating melatonin levels in chicks and rats: evidence for stimulation of melatonin synthesis and release in the gastrointestinal tract. *Life Sci*. 1992;51(12):945-953. doi:10.1016/0024-3205(92)90442-8
31. Javed U. Effect of tryptophan supplementation on growth performance of meat type birds: a review. *J Glob Innov Agric Soc Sci*. 2020;8(3):135-139. doi:10.22194/JGIASS/8-911
32. Jiang SQ, Gou ZY, Lin XJ, Li L. Effects of dietary tryptophan levels on performance and biochemical variables of plasma and intestinal mucosa in yellow-feathered broiler breeders. *J Anim Physiol Anim Nutr (Berl)*. 2018;102(1):e387-e394. doi:10.1111/jpn.12853
33. Jwad MM, Al-Ruby SH, Kutar AH, Al-Azawi TS. Improvement of the blood characteristics of broiler chickens by addition of tryptophan acid supplement levels in ration. Iraqi J Sci. 2012;9(1):45-9. doi:10.21123/bsj.9.1.45-49
34. Khalil MM, Abdollahi MR, Zaefarian F, Ravindran V. Influence of feed form on the apparent metabolisable energy of feed ingredients for broiler chickens. *Anim Feed Sci Technol*. 2021;271:114754. doi:10.1016/j.anifeedsci.2020.114754
35. Khattak F, Helmbrecht A. Effect of different levels of tryptophan on productive performance, egg quality, blood biochemistry, and caecal microbiota of hens housed in enriched colony cages under commercial stocking density. *Poult Sci*. 2019;98(5):2094-2104. doi:10.3382/ps/pey562
36. Lee YJ. Tissue-specific effects of melatonin on the activity of antioxidant enzymes in male C57BL/6 mice. *J Ind Technol Res*. 2025;30(1):107–114. doi:10.29279/jitr.k.2025.30.1.107
37. Li Q, Ouyang J, Deng C, Zhou H, You J, Li G. Effects of dietary tryptophan supplementation on rectal temperature, humoral immunity, and cecal microflora composition of heat-stressed broilers. Front Vet Sci. 2023;10:1247260. doi: 10.3389/fvets.2023.1247260
38. Li W, Yuan L, Jin W, Wang B, Li G, Li S, Kang X, Li W. Intestinal differential metabolite tryptophan from avian pathogenic *Escherichia coli* (APEC)-resistant and susceptible chickens alleviates APEC symptoms in chickens. *Poult Sci*. 2025;104(7):105212. doi:10.1016/j.psj.2025.105212
39. Li X, Zhang ZH, Zabed HM, Yun J, Zhang G, Qi X. An insight into the roles of dietary tryptophan and its metabolites in intestinal inflammation and inflammatory bowel disease.

Mol Nutr Food Res. 2021;65(5):e2000461. doi:10.1002/mnfr.202000461
40. Linh NT, Guntoro B, Qui NH. Immunomodulatory, behavioral, and nutritional response of tryptophan application on poultry. *Vet World*. 2021;14(8):2244-2250. doi:10.14202/vetworld.2021.2244-2250
41. Lisnahan CV, Nahak OR. Growth performance and small intestinal morphology of native chickens after feed supplementation with tryptophan and threonine during the starter phase. *Vet World*. 2020;13(12):2765-2771.
42. Liu J, Zhang Y, Li Y, Yan H, Zhang H. L-tryptophan enhances intestinal integrity in diquat-challenged piglets associated with improvement of redox status and mitochondrial function. *Animals (Basel)*. 2019;9(5):266. doi:10.3390/ani9050266
43. Liu Y, Yuan JM, Zhang LS, Zhang YR, Cai SM, Yu JH, Xia ZF. Effects of tryptophan supplementation on growth performance, antioxidative activity, and meat quality of ducks under high stocking density. *Poult Sci*. 2015;94(8):1894-1901. doi:10.3382/ps/pev153
44. Ma D, Zhang S, Zhang M, Feng J. Dietary tryptophan alleviates intestinal inflammation caused by long photoperiod via gut microbiota derived tryptophan metabolites-NLRP3 pathway in broiler chickens. Poult Sci. 2024 Apr;103(4):103509. doi: 10.1016/j.psj.2024.103509
45. Mehaisen GM, Eshak MG, Elkaiaty AM, Atta ARM, Mashaly MM, Abass AO. Comprehensive growth performance, immune function, plasma biochemistry, gene expressions and cell death morphology responses to a daily corticosterone injection course in broiler chickens. *PLoS One*. 2017;12(3):e0172684. doi:10.1371/journal.pone.0172684
46. Mund MD, Riaz M, Mirza MA, Rahman ZU, Mahmood T, Ahmad F, Ammar A. Effect of dietary tryptophan supplementation on growth performance, immune response and antioxidant status of broiler chickens from 7 to 21 days. *Vet Med Sci*. 2020;6(1):48-53. doi:10.1002/vms3.207
47. Nayak BN, Singh RB, Buttar HS. Biochemical and dietary functions of tryptophan and its metabolites in human health. In: Functional Foods and Nutraceuticals in Metabolic and Non-Communicable Diseases. 2022:783-798. doi:10.1016/B978-0-12-819815-5.00003-3
48. Ouyang J, Zhou H, Li Q, Zheng J, Chen C, Guo S, You J, Li G. Tryptophan alleviates acute heat stress-induced impairment of antioxidant status and mitochondrial function in broilers. *Front Vet Sci*. 2022;9:863156. doi:10.3389/fvets.2022.863156
49. Pan X, Wei Z, Wang H, Yu L, Liang X. Effects of dietary tryptophan on protein metabolism and related gene expression in Yangzhou goslings under different feeding regimens. *Poult Sci*. 2013;92(12):3196-3204. doi:10.3382/ps.2013-03268
50. Ricci FG, Terkelli LR, Venancio EJ, Justino L, dos Santos BQ, Baptista AAS, Oba A, de Oliveira Souza BD, Bracarense APFRL, Hirooka EY, Itano EN. Tryptophan attenuates the effects of OTA on intestinal morphology and local IgA/IgY production in broiler chicks. *Toxins (Basel)*. 2021;13(1):5. doi:10.3390/toxins13010005
51. Sato H, Miura M, Fujieda T, Taciak M, Kikusato M, Sato K, Toyomizu M. Growth performance responses to increased tryptophan supplementation in growing barrows fed three different very low crude protein corn and soybean meal-based diets fortified with essential amino acids. *Anim Sci J*. 2021;92(1):e13605. doi:10.1111/asj.13605
52. Schwarcz R, Bruno JP, Muchowski PJ, Wu HQ. Kynurenines in the mammalian brain: when physiology meets pathology. *Nat Rev Neurosci*. 2012;13(7):465–77. doi:10.1038/nrn3257
53. Soleimani AF, Zulkifli I, Omar AR, Raha AR. The relationship between adrenocortical function and hsp70 expression in socially isolated Japanese quail. *Comp Biochem Physiol B Biochem Mol Biol*. 2012;161(2):140-144. doi:10.1016/j.cbpb.2011.11.001

54. Soleimani AF, Zulkifli I, Hair-Bejo M, Omar AR, Raha AR. The role of heat shock protein 70 in resistance to *Salmonella enteritidis* in broiler chickens subjected to neonatal feed restriction and thermal stress. *Poult Sci*. 2012;91(2):340-345. doi:10.3382/ps.2011-01827
55. Strasser B, Gostner JM, Fuchs D. Mood, food, and cognition: role of tryptophan and serotonin. *Curr Opin Clin Nutr Metab Care*. 2016;19(1):55-61. doi:10.1097/MCO.0000000000000237
56. Tan DX, Manchester LC, Esteban-Zubero E, Zhou Z, Reiter RJ. Melatonin as a potent and inducible endogenous antioxidant: synthesis and metabolism. *Molecules*. 2015;20(10):18886–18906. doi:10.3390/molecules201018886
57. Timosenko E, Ghadbane H, Silk JD, Shepherd D, Gileadi U, Howson LJ, Laynes R, Zhao Q, Strausberg RL, Olsen LR, Taylor S, Buffa FM, Boyd R, Cerundolo V. Nutritional stress induced by tryptophan-degrading enzymes results in ATF4-dependent reprogramming of the amino acid transporter profile in tumor cells. *Cancer Res*. 2016;76(21):6193-6204. doi:10.1158/0008-5472.CAN-15-3502
58. van Hierden YM, Koolhaas JM, Korte SM. Chronic increase of dietary L-tryptophan decreases gentle feather pecking behaviour. *Appl Anim Behav Sci*. 2004;89(1-2):71-84. doi:10.1016/j.applanim.2004.04.004
59. Wang B, Min Z, Yuan J. Apparent ileal digestible tryptophan requirements of 22- to 42-day-old broiler chicks. *J Appl Poult Res*. 2016;25(1):54-61. doi:10.3382/japr/pfv067
60. Wang B, Min Z, Yuan J, Zhang B, Guo Y. Effects of dietary tryptophan and stocking density on the performance, meat quality, and metabolic status of broilers. *J Anim Sci Biotechnol*. 2014;5:44. doi:10.1186/2049-1891-5-44
61. Wang XF, Zhu XD, Li YJ, Liu Y, Li JL, Gao F, Zhou GH, Zhang L. Effect of dietary creatine monohydrate supplementation on muscle lipid peroxidation and antioxidant capacity of transported broilers in summer. *Poult Sci*. 2015;94(11):2797-2804. doi:10.3382/ps/pev265
62. Wecke C, Liebert F. Improving the reliability of optimal in-feed amino acid ratios based on individual amino acid efficiency data from N balance studies in growing chicken. *Animals (Basel)*. 2013;3(3):558-573. doi:10.3390/ani3030558
63. Yıldırım A, Kraimi N, Constantin P, Mercerand F, Leterrier C. Effects of tryptophan and probiotic supplementation on growth and behavior in quail. *Poult Sci*. 2020;99(11):5206-5213. doi:10.1016/j.psj.2020.07.044
64. Yue Y, Guo Y, Yang Y. Effects of dietary L-tryptophan supplementation on intestinal response to chronic unpredictable stress in broilers. *Amino Acids*. 2017;49(7):1227-1236. doi:10.1007/s00726-017-2424-3
65. Zuidhof MJ, Schneider BL, Carney VL, Korver DR, Robinson FE. Growth, efficiency, and yield of commercial broilers from 1957, 1978, and 2005. *Poult Sci*. 2014;93(1):1–13. doi:10.3382/ps.2014-04291