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L-Carnitine and Its Use as A Feed Additive in Broiler Chicken Diet: A Review

Dr. Dhrumilkumar Panchal*, Dr. Safimahmad Vahora, Dr. Rutvi Patel, Dr. Nayan Raval, Dr. Ashish Patel, Dr. Akashkumar Sutariya
Department of Animal Nutrition, College of Veterinary Science & A. H., Kamdhenu University, Anand, Gujarat, India
***Corresponding author:** dhrumilppanchal@gmail.com
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Abstract

L-carnitine is an amino acid–derived, vitamin-like compound that plays a crucial role in intermediary metabolism, particularly in mitochondrial fatty acid transport and energy production. Although endogenously synthesized from lysine and methionine, its production may be inadequate in poultry under intensive production systems due to high metabolic demands and limited dietary availability. In broiler chickens, L-carnitine facilitates the transport of long-chain fatty acids into mitochondria for β-oxidation, thereby enhancing energy utilization, sparing essential amino acids and supporting protein synthesis. Dietary supplementation with L-carnitine has been widely investigated for its effects on growth performance, feed efficiency, fat metabolism, immune response and antioxidant capacity, although responses vary depending on dietary composition, supplementation level and physiological conditions in birds. Overall, L-carnitine supplementation represents a promising nutritional strategy to improve metabolic efficiency, health status and productive performance in broiler chickens.

Keywords: L-carnitine, Growth performance, Lipid metabolism, Immune response, Oxidative stress

1. Introduction

L-carnitine (β-hydroxy-γ-N-trimethylaminobutyrate) is an amino acid–derived, vitamin-like compound that has gained considerable scientific attention in animal nutrition because of its central role in intermediary metabolism and its potential to enhance productive performance in livestock and poultry (Arslan, 2006). Traditionally, vitamins are defined as organic compounds required in small quantities to support normal metabolic functions with deficiencies leading to specific pathological conditions. Although L-carnitine can be synthesized within the body, it is considered a “conditionally essential” nutrient in certain

species and physiological states, particularly under conditions of rapid growth or high metabolic demand. It exists in both free and esterified forms and is synthesized endogenously, primarily in the liver, from the essential amino acid's lysine and methionine (Bremer, 1983). This biosynthetic process is dependent on several micronutrient cofactors, including ferrous ion, ascorbic acid, niacin and pyridoxine underscoring the complex nutritional interdependence involved in its metabolism. The historical discovery of L-carnitine in skeletal muscle by Gulewitsch and Krimberg in 1905 marked a significant milestone in nutritional biochemistry and laid the groundwork for subsequent research into its biological roles (Gulewitsch & Krimberg, 1905).

In poultry, the physiological importance of L-carnitine is particularly evident. Early studies reported high concentrations of L-carnitine in chicken embryos, suggesting a critical role in embryonic development and early growth (Rezaei *et al*., 2008). Despite its endogenous synthesis, chickens appear to have a limited capacity to produce adequate quantities of L-carnitine to meet metabolic demands, especially under intensive production systems. Furthermore, modern poultry diets are predominantly based on cereal grains, which are inherently poor sources of L-carnitine, thereby increasing the likelihood of marginal deficiency under practical feeding conditions (Golzar Adabi *et al*., 2006b). The reliance on lysine and methionine often the first limiting amino acids in poultry rations further constrains endogenous synthesis, reinforcing the nutritional relevance of dietary L-carnitine supplementation.

The mechanisms of intestinal absorption of L-carnitine remain an area of ongoing scientific debate, with evidence supporting both active and passive transport systems. Functionally, L-carnitine is indispensable for lipid metabolism, as it facilitates the transport of long-chain fatty acids across the inner mitochondrial membrane, enabling β-oxidation and cellular energy generation (Neuman *et al*., 2002; Sarica *et al*., 2005; Arslan, 2006). In addition to its role in energy metabolism, L-carnitine contributes to mitochondrial homeostasis by aiding in the removal of potentially toxic acyl groups, thereby protecting mitochondrial integrity and overall cellular health. Through these diverse and interconnected mechanisms, L-carnitine has been widely investigated as a nutritional strategy to improve growth performance, feed efficiency and metabolic health in poultry.

2. Chemical Structure of L-carnitine

L-carnitine ($C_7H_{15}NO_3$) is distributed in plasma and body tissues either as free carnitine or in esterified forms bound to fatty acids, known as acyl-carnitines (Tomita & Sendju, 1927; Bieber, 1988). It is a water-soluble zwitter ion with a molecular mass of 161.2

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M_R and has been recognized for its physiological importance for almost a century; however, several aspects of its involvement in health and disease processes remain incompletely understood (Mast *et al*., 2000). The presence of a chiral center at the second carbon atom confers optical activity, resulting in two enantiomeric forms. The D-isomer is absent in nature and produced only through chemical synthesis (Liedtke *et al*., 1982) while the L-isomer is the naturally occurring and biologically active form responsible for the nutritional and pharmacological effects of carnitine (Mardones *et al*., 1999). Subsequent research has indicated that D-carnitine competitively interferes with the active transport systems involved in L-carnitine uptake (Walter & Schaffhauser, 2000).

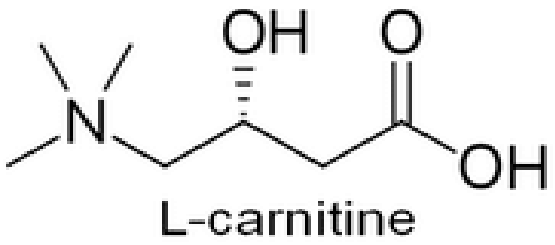

Figure 1: Structural Formula of L-carnitine (L-3-hydroxy-4-N-trimethylaminobutyrate)

3. Biosynthesis of L-carnitine

Synthesis of Carnitine is endogenous and requires two amino acids lysine and methionine. Lysine is the supplier of the carbon chain and the hydrogen atom and methionine also play a role as a methyl donor in this process (Flanagan *et al*., 2010). Carnitine has two L and D isomers, the L isomer being important for humans and animals. It synthesized *in vivo* from lysine and methionine in the kidney (feline, man), testes (rat), skeletal muscle (sheep), brain (man) and liver in all mammals. During the synthesis L-lysine provides the carbon chain and nitrogen atom of carnitine and L-methionine provides the methyl groups.

The conversion of TrimethylLysine to carnitine requires 2 hydroxylations catalysed by 2 specific monooxygenases that use α ketoglutarate as an electron donor to activate dioxygen. The α-amino acids is cleared into CO_2 and succinate. The both enzymes require Fe^{+2} and are activated by ascorbate. Endogenous biosynthesis may be sufficient to cover normal requirements in all mammals and bird species, when precursors and cofactors of the L-carnitine is sufficient in the diet. However, this is not the case in neonates (in which the biosynthesis is not fully developed) (Arslan, 2006). L-carnitine per kilogram of poultry feed

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is 2 to 5 milligrams and an average requirement is 25 to 50 milligrams per day (Mirzapor Sarab *et al*.,
2016).

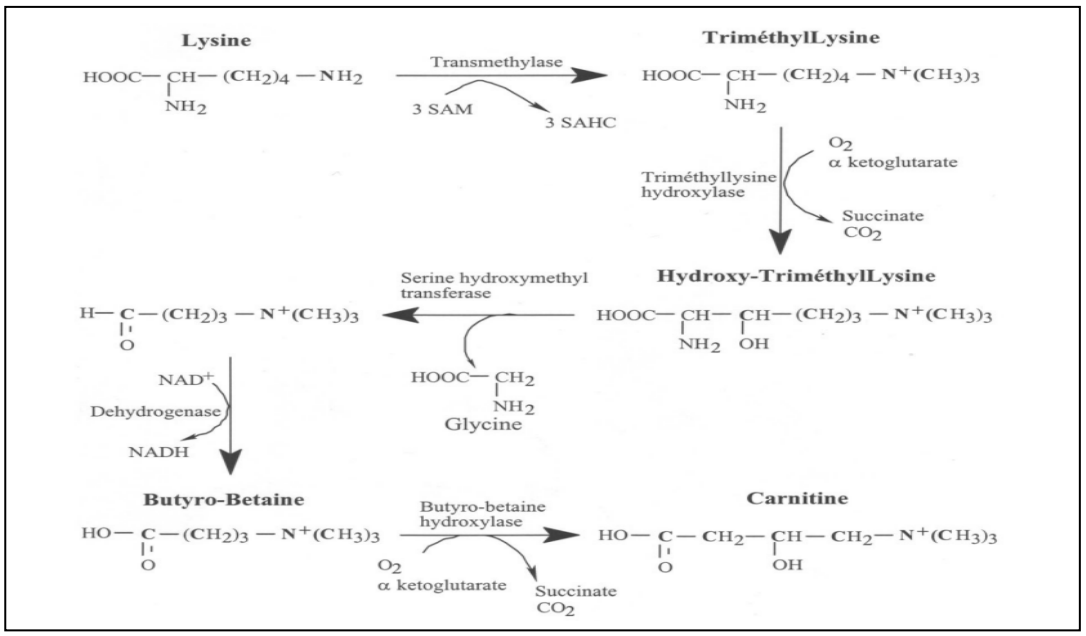

Figure 2: Biosynthesis of L-carnitine

4. General Functions of L-carnitine in Broiler Chicken

L-carnitine participates in several metabolic reactions, its most widely known function is probably interference in the overall context of normal fatty acid metabolism (Zeyner and Harmeyer, 1999; Hoppel, 2003). A major factor controlling the oxidation of fatty acids is the rate of entry into the mitochondria. While some long-chain fatty acids (perhaps 30% in total) enter mitochondria and are converted to CoA derivatives in the matrix, the majority are 'activated' to acyl-CoA derivatives on the inner surface of the outer membranes of the mitochondria (Metzler and Metzler, 2003). L-carnitine serves as the carrier that transports activated long chain fatty acyl groups across the inner mitochondrial membrane. L-carnitine acyl transferases are able to reversibly transfer an activated fatty acyl group from CoA to the hydroxyl group of carnitine to form an acylcarnitine ester. The reaction is reversible, so that the fatty acyl CoA derivative can be regenerated from the carnitine ester.

Carnitine palmitoyl transferase I (CPTI; also called carnitine acyltransferase I), the enzyme that transfers long-chain fatty acyl groups from CoA to carnitine, is located on the outer mitochondrial membrane. Fatty acylcarnitine crosses the inner mitochondrial membrane with the aid of a translocase. The fatty acyl group is transferred back to CoA by a second enzyme carnitine palmitoyl transferase II (CPTII or CATII). The carnitine released in this reaction returns to the cytosolic side of the mitochondrial membrane by the same translocase

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that brings fatty acylcarnitine to the matrix side. Long-chain fatty acyl CoA now located within the mitochondrial matrix is a substrate for β-oxidation (Smith *et al*., 2004).

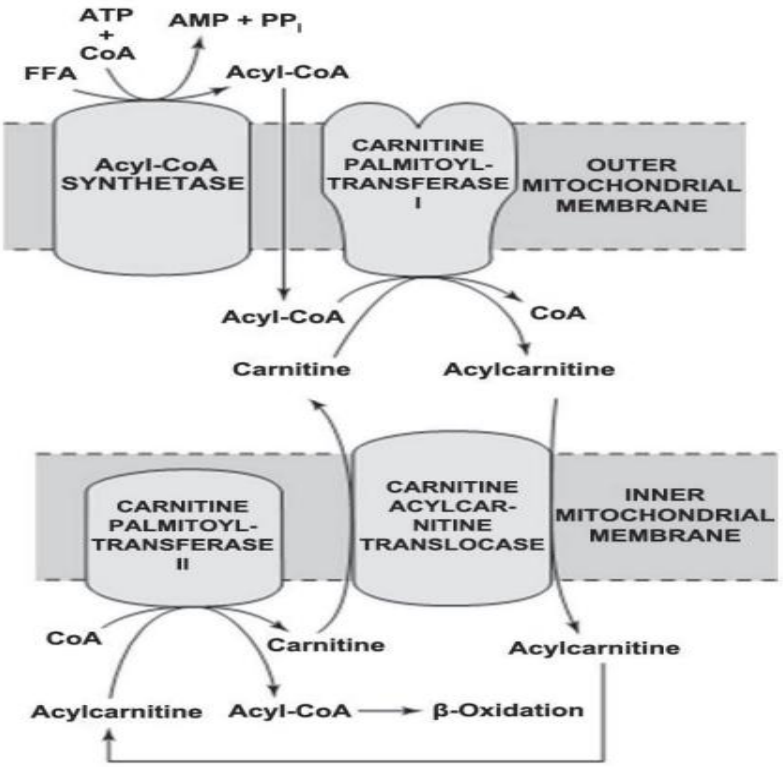

Figure 3: Role of L-carnitine in the Transport of Long-Chain Fatty Acids through the Inner Mitochondrial Membrane

Exogenous carnitine supply can decrease the need of methionine & lysine for biosynthesis of carnitine, thus sparing methionine for other biological functions (La Count *et al*., 1995). Enhanced fatty acid oxidation should inhibit BCKDH (branch chain ketoacid dehydrogenase) activity by elevating concentrations of acetyl CoA, NADH and ATP and thereby reduce the oxidation of branched-chain amino acids. These changes favour amino acid synthesis over degradation, which could promote protein synthesis (Owen *et al*., 2001).

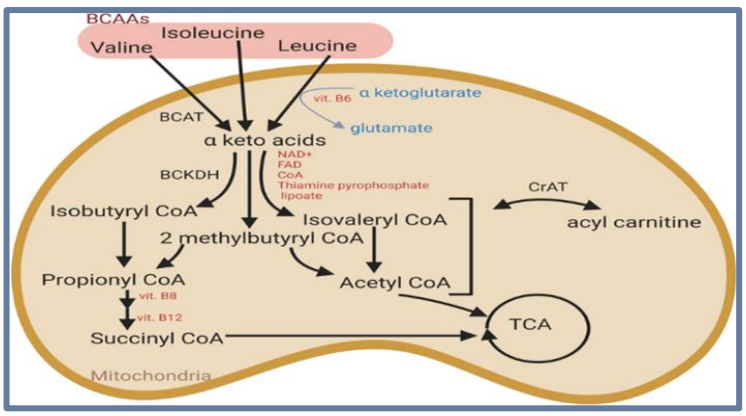

Figure 4: Breakdown of Branch Chain Amino Acids

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5. Effects of L-carnitine in Broiler Chicken

5.1 Growth performance

Feed efficiency is a key trait in commercial animal production because feed accounts for approximately 60–70% of the total cost of raising animals to market weight. Since mitochondria generate about 90% of cellular energy, differences in broiler growth performance and feed efficiency may be partly related to variations in mitochondrial function (Bottje *et al*., 2002). As discussed earlier, L-carnitine plays an important role in energy metabolism by enhancing mitochondrial fatty acid oxidation, thereby improving energy utilization (Bremer, 1962; 1983). For this reason, L-carnitine has been proposed as a dietary supplement in poultry nutrition to improve performance; however, published studies report inconsistent results regarding the extent or even the presence of such benefits.

Several studies have evaluated the effects of dietary L-carnitine supplementation on feed intake, growth performance and feed conversion efficiency in broiler chickens, with variable results. Regarding feed intake, El-Damrawy (2024) and Warmazyar *et al*. (2018) reported no significant effects in broilers, respectively, whereas Ismail and Ouda (2020), Sikder *et al.* (2018) and El-Kelawy (2017) observed a significant reduction in feed intake, particularly at moderate to higher supplementation levels.

In terms of growth performance, El-Damrawy (2024) reported significantly higher body weight and body weight gain at 35 days in broilers supplemented with 25 mg/kg L-carnitine. Similarly, Sikder *et al*. (2018) and El-Kelawy (2017) documented significant improvements in body weight and weight gain in L-carnitine supplemented groups with optimal responses generally observed at lower to moderate levels. In contrast, Warmazyar *et al.* (2018) did not observe significant improvements in body weight of chickens.

Feed conversion ratio (FCR) responses were more consistent, with El-Damrawy (2024), Ismail and Ouda (2020), Sikder *et al.* (2018) and El-Kelawy (2017) reporting significant improvements in FCR following L-carnitine supplementation. However, Warmazyar *et al.* (2018) observed non significant effect on FCR.

Several hypotheses have been proposed to explain the mechanisms by which L-carnitine may enhance growth performance in broiler chickens. Improvements in body weight gain reported in some studies may be linked to more efficient utilization of dietary nitrogen, resulting from enhanced mitochondrial fatty acid oxidation mediated by L-carnitine. Increased oxidation of fatty acids may reduce their availability for triacylglycerol synthesis while simultaneously elevating mitochondrial acetyl-CoA concentrations. Elevated acetyl-CoA can stimulate the activity of pyruvate carboxylase, an acetyl-CoA-dependent enzyme involved in

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providing carbon skeletons for amino acid synthesis (Cyr *et al.,* 1991). In addition, improved growth following L-carnitine supplementation may be partly attributed to its amino acid sparing effect, in addition to its role in lipid metabolism. Exogenous L-carnitine supplementation may reduce the requirement for endogenous synthesis from methionine, thereby conserving methionine for other essential metabolic functions (La Count *et al.,* 1995).

The variable effects of L-carnitine supplementation on growth performance may be explained by differences in supplementation level, basal dietary carnitine content and the nutritional and physiological status of the birds. Other contributing factors include diet composition, availability of essential amino acids, interactions with amino acid metabolism, and the sparing effects of L-carnitine and its precursors, lysine and methionine. In addition, age, sex, feeding strategy and management or environmental conditions may influence the response to supplementation (Rabie *et al*., 1997c; Owen *et al*., 2001; Rodehutscord *et al*., 2002; Xu *et al*., 2003; Celik & Ozturkcan, 2003). Nevertheless, the precise reasons for these inconsistent findings remain unclear (Fischer *et al*., 2009).

5.2 Fat metabolism

Dietary L-carnitine supplementation has been shown to improve carcass traits and lipid metabolism in broiler chickens by reducing fat deposition. Several studies reported significant reductions in abdominal fat and improvements in dressed weight following L-carnitine supplementation (El-Damrawy, 2024; Sikder *et al*., 2018; El-Kelawy, 2017). In addition, L-carnitine favorably altered lipid profiles by lowering serum total lipids, triglycerides, cholesterol and LDL levels, while increasing HDL concentrations, particularly at moderate to higher inclusion levels (Ismail & Ouda, 2020; El-Kelawy, 2017).

5.3 Immune system

L-carnitine plays an important role in regulating immune function in broiler chickens by supporting both cellular and humoral immune responses. It is present at high concentrations in lymphocytes, where it reduces apoptosis and enhances immune cell proliferation (De Simone *et al*., 1994). Dietary supplementation of L-carnitine has been shown to increase immunoglobulin levels (IgG and IgA), enhance antibody titers against sheep red blood cells and Newcastle disease virus and increase the relative weights of major immune organs, including the bursa of Fabricius, spleen, and thymus (Mast *et al*., 2000; Golzar Adabi *et al*., 2006b). Supporting these findings, Sikder *et al*. (2018) reported significantly higher spleen and thymus weights in broilers supplemented with moderate to higher levels of L-carnitine, while El-Kelawy (2017) observed significant improvements in immunological parameters such as total protein, γ-globulin, IgM and IgG in L-carnitine supplemented groups.

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Collectively, these results indicate that L-carnitine supplementation enhances immune organ development and immune competence in broiler chickens.

5.4 Antioxidant capacity

L-carnitine plays a significant role in alleviating oxidative stress by enhancing mitochondrial fatty acid metabolism and activating nuclear factor erythroid 2 related factor 2 (Nrf2), a key transcription factor regulating cellular antioxidant defenses (Chen *et al*., 2015). Upon activation, Nrf2 translocates to the nucleus and binds to antioxidant response elements (ARE), thereby upregulating the expression of endogenous antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx). In addition, L-carnitine buffers excess acetyl-CoA, the accumulation of which can promote free radical formation and cellular toxicity and protects against lipid peroxidation by reducing hydrogen peroxide production (Zeyner & Harmeyer, 1999). Furthermore, L-carnitine and its esters may inhibit Fe^{2+} induced lipid peroxidation by chelating free iron ions, thereby limiting reactive oxygen species formation through the Haber–Weiss reaction.

Experimental evidence in broiler chickens supports these antioxidant effects. Hasani *et al.* (2025) reported significantly reduced malondialdehyde (MDA) levels and increased nitrite concentrations in Ross 308 broilers supplemented with L-carnitine under high-altitude conditions indicating reduced lipid peroxidation and improved redox status. Similarly, El-Kelawy (2017) observed significantly higher activities of antioxidant enzymes, including GPx, glutathione (GSH) and SOD in Cobb broilers fed diets supplemented with 50–150 mg/kg L-carnitine. Consistent with these findings, Wang *et al.* (2013) demonstrated enhanced GPx and total SOD activities in Ross 308 broilers supplemented with 100 mg/kg L-carnitine under cold stress conditions. Collectively, these studies indicate that dietary L-carnitine enhances antioxidant capacity in broilers, particularly under environmental stress, through both direct and Nrf2-mediated mechanisms.

6. Conclusions

Based on the above study, it can be concluded that dietary L-carnitine plays a significant role in improving metabolic efficiency in broiler chickens by enhancing mitochondrial fatty acid oxidation and energy utilization. Supplementation with L-carnitine consistently improves feed conversion ratio, reduces fat deposition and supports immune function and antioxidant defense mechanisms. The most consistent and optimal responses are observed at dietary inclusion levels ranging from 25 to 100 mg/kg feed**,** particularly at lower to moderate supplementation rates. Therefore, L-carnitine may be considered an effective

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functional feed additive for enhancing performance and overall health in broiler chickens under intensive production systems.

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