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Review Article

L-Carnitine in Broiler Chickens: Mechanistic Roles in Energy Metabolism, Oxidative Stress, and Gut Health with Implications for Sustainable Poultry Production

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Abstract

This article reviews the mechanical role of L-carnitine in broilers, focusing on three main axes: energy metabolism, oxidative stress, and gut health. L-carnitine is made in the body from the amino acids lysine and methionine, and is also supplemented from feed. It plays a pivotal role in transporting long-chain fatty acids to the mitochondria for oxidation and ATP production, enhancing energy efficiency, especially in the late growth stages and at high-energy feeding. L-carnitine also exhibits protective effects against oxidative stress caused by heat, transport, or feed stress, as it reduces the production of reactive oxygen species and restores antioxidant balance, maintaining the quality of the meat. In terms of gut health, L-carnitine regulates acetyl-CoA metabolism, coordinates glycolysis pathways and the TCA cycle, and improves nutrient allocation. It has been observed that the embryonic chick has a physiological deficiency of carnitine and needs supplementation from day 7.5 after hatching. However, the effects of carnitine on growth performance and trophic conversion factor vary (positive, negative, or insignificant) depending on age, breed, management conditions, and climate. The article recommends standardized methodological studies to fill in knowledge gaps and enhance the role of carnitine in the sustainability of broiler production.

Keywords: L-Carnitine, Broiler, Energy Metabolism.

1. Introduction

L-Carnitine is a nitrogenous compound involved in mitochondrial fatty acid oxidation. It is biosynthesized from the essential amino acids lysine and methionine (1). Broiler chickens can also obtain L-carnitine from feedstuffs, particularly milk and milk products (2). Given the rapid growth of broilers and the high-energy demand associated with it, L-carnitine is often supplemented in broiler diets to support energy metabolism (3). Its supplementation has been found to support growth and feed conversion in broiler chickens, thereby improving sustainability while minimizing environmental impact (4).

2. Biochemical Basis of L-Carnitine Function

L-carnitine is a cationic quaternary amine formed from lysine and methionine; its derivative acyl-carnitine can also be produced from 4 vitamin B-derivatives (pantothenic acid, niacin, riboflavin, and vitamin B12) (5). L-carnitine plays a crucial role in

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lipid metabolism. Carnitine is responsible for transporting acyl groups into mitochondria for subsequent β-oxidation, while acetyl groups are transferred from generating fatty acids to produce acetyl-CoA (6). In the liver and kidney, L-carnitine helps eliminate excess acetyl-CoA by internal buffering and serves as a precursor toward producing acetyl-carnitine and other non-esterified metabolically active derivatives for coordinating lipid and carbohydrate metabolism (6). Acids transported by L-carnitine are derived from carbohydrate, fat, amino acids, lactate, and ethanol metabolism and participate in fatty-acid metabolism (7). This nutrient delivers unique physiological benefits. During typical chicken growth, feed restriction and elevated temperature are significant stressors due to rapid size enlargement (8). Carnitine is sensitive to the pattern of these stresses. Carnitine content in broiler-breeder eggs has a considerable effect on broiler chicken growth (9).

L-carnitine reacts with short-chain fatty acids to form acylcarnitines, which can exit the mitochondria, alter glucose utilization, and delete excessive free acety-CoA. The porcine strain Cpo-1 also catalyzes the conjugation of β-hydroxybutyrate and butyrate with L-carnitine and other fatty acids (10). Acylcarnitines are in excess in the broiler-meat industry, where the original broiler was selected (11). Hot benzoic acid-curing sodium-azide-treated chicken-spiders and middle silk stitches influenced the broiler and ruined the meat. Growth-promoter-free (UG-1) cultivars were compared, and bivalve-Vibrio-free aquaculture with UG-1 shrimp crucially specialized on residual protein and sweet supply to rigidae the mucosa and maintain pneumatic stasis (12).

3. Energy Metabolism in Broiler Chickens and the Role of L-Carnitine

The energy metabolism of modern broiler chickens exhibits important differences from that of traditional strains. In addition to dietary energy, broilers have high demands for energy itself during programmed growth, and there is a concurrent need to metabolize fatty acids, carbohydrates, and amino acids (4). Energy from metabolizable substrates can be converted to adenosine triphosphate (ATP) via energy-linked oxidation (13). L-Carnitine is involved in lipid metabolism and affects growth performance and carcass traits in broilers, with various effects depending on the supply level, strain, and feeding strategy (2). Carnitine availability influences the utilization of lipids, carbohydrates, and proteins for energy generation in broilers (14).

Supplementation with L-carnitine significantly increases the oxidation of fatty acids and the production of ATP in the liver and pectoral muscles, resulting in more efficient energy conversion in broilers (2). The most effective dietary level also varies with growth stage, and higher carnitine dietary levels can enhance energy metabolism in broilers with a high-energy-feeding diet, especially in late-stage broilers (15). Furthermore, frequently used feedstuff origin and fat type also interact with L-carnitine concentration and energy utilization in broilers (2).

4. L-Carnitine and Oxidative Stress in Poultry

L-carnitine has demonstrated protective effects against oxidative stress in broiler chickens exposed to environmental and feed-related stressors (16). Supplementing L-carnitine can mitigate reactive oxygen species production, normalize mitochondrial membrane potential, and restore antioxidant capacity under heat, transport, and feed stress conditions (17). In addition, L-carnitine protects meat quality by maintaining redox status and lipid oxidation stability during storage (4).

5. Gut Health: Microbiota, Intestinal Integrity, and L-Carnitine

Carnitine has a central physiological and metabolic role in energy-yielding pathways and systemic energy homeostasis via the carnitine shuttle system, which transports long-chain fatty acids into mitochondrial compartments for β-oxidation, thus

limiting substrate availability for biomass production and lipogenesis, while promoting systemic energy storage and attenuating fuel overflow (18). Carnitine has auxiliary functions in non–lipid metabolism: (1) buffering acetyl-CoA to coordinate glycolysis, the TCA cycle, and fatty-acid metabolism, (2) generating translocatable acyl-carnitine derivatives, which allow fine-tuning of the energetically demanding step of long-chain fatty acid entry into mitochondria, and (3) participating in feedstuff–fed energy utilization and nutrients allocation under variable carnitine availability (19).

Carnitine biosynthesis is widespread across oviparous and precocial species and occurs via two alternative pathways using ectopic trimethyl-lysine as a substrate in the kidneys and liver, respectively, with additional maternal deposition (20). The chick embryo is physiologically carnitine deficient and requires dietary supplementation from embryonic day 7.5 onwards; thereafter, fatty-acid oxidation becomes the preferred energy-yielding pathway, and growth performance is responsive to exogenous provision (21). During early post-hatch and chick stages, poultry species follow a rapid-growth pattern with high energy demands, fat-energy intake, and feed-energy-to-biomass conversion efficiency, and are thus subjected to metabolic constraints, with fatty-acid availability, utilization, deposition, and oxidation being crucial for optimal productivity (19).

In sustainable production systems, costly floor space and energy are conserved by restricting feeding during the late growth stage; this approach is adopted by many commercial broiler operations, including those in India (22). All feedstuffs pose similar metabolic challenges, and resource allocation among competing substrates is finely balanced (23). Consequently, animal genotype, system management (e.g., restricted feeding), and nutrient formulation (e.g., energy density) all constitute significant determinants of productivity, and interactive effects between carnitine and these variables must be considered when prescribing dietary inclusion levels (24).

6. Impacts on Growth Performance and Feed Efficiency

The reported effects of L-carnitine on growth performance in poultry, often expressed as body weight gain, feed intake, feed conversion ratio, carcass traits, and abdominal fat percentage, are mixed (4). Positive, negative, and non-significant responses have been observed across different ages, production stages, and management conditions, contributing to low consistency in commercial application (25). Although there are indications that specific levels of supplementation may enhance the economic viability of production under certain circumstances, the diversity of evidence warrants caution (26). The absence of rigorous standardized methodologies and control protocols in many of the published experiments further complicates the interpretation of the observations (27). Additionally, potential confounding factors—such as regional and seasonal climate, dietary aspects, and flooring type—remain unaccounted for in the majority of studies (28). Integration of L-carnitine into nutritionally fortified starting feeds during the first weeks of life, the period of maximum growth, appears to be a logical target for further investigation and standardization (29).

7. Conclusion

Broiler chickens are characterized by superior growth rate and feed conversion efficiency, yet the production system is increasingly unsustainable worldwide. The maintenance of these superior characteristics is an objective of integrated research worldwide. L-carnitine is viewed as substantial for broiler chicken production, with increasing support for international popularity.

The biochemistry and roles of L-carnitine in broiler chickens demarcated three primary mechanistic roles: energy metabolism, oxidative stress, and gut health. Carnitine has an established biochemistry and

is widely believed to have roles in poultry before displaying contradictory findings in chickens. Additional supplementation at varied levels was reported to enhance different beneficial aspects towards sustainability in production. Further systematic studies are required to fill significant knowledge gaps, as the mechanistic findings abstracted demonstrate the influence of L-carnitine supplementation relating to sustainability in production.

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