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Effects of L-carnitine supplementation in diets of broiler chickens

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ABSTRACT: L-carnitine is a nutritional supplement having fat-burning property and plays an important role in lipid metabolism, energy release, and also improve the production yield, immunity and blood constitute. This paper reviews the effects of L-carnitine on quantitative and qualitative characteristics of broilers. According to the reviewed literature, the application of L-carnitine (50-200 mg/kg) has no significant effect on the growth performance, however, using L-carnitine as much as 300-800 mg/kg resulted to an improvement in the body weight (2226.00-2575.00 g) compared to the control chicks (1998.40-2338.75 g). The feed conversion ratios of the chickens fed the same amount of L-carnitine were 1.66-1.86 kg/kg, which was improved in comparison with the control chicks (1.87-2.09 kg/kg). Abdominal fat of the broiler chickens fed 50-900 mg/kg L-carnitine was 0.98-1.75%, which is lower than the control chicks (1.79-2.16%). For immunity, the antibody titers against the Newcastle virus in the chickens fed 250 mg/kg L-carnitine was between 4.6- 5.5 which is more than control chicks (4.3-5.2). The antibody titer against the influenza virus in the chickens fed the same amount of L-carnitine was between 5.6-6.3, which was more than the control chicks (4.3-5.8). The use of 100-600 mg/kg L-carnitine could reduce triglyceride (90-104.4 mg/dL) compared to the control chicks (125-104.7 mg/dL) and also reduced the cholesterol (109-115 mg/dL) compared to the control chicks (129.25-131 mg/dL). The application of 100-600 mg/kg L-carnitine also could reduce low-density lipoprotein (LDL) from 19.1-72.2 mg/dL to 16.5-49.0 mg/dL. However, the application of 100-900 mg/kg L-carnitine had no significant effect on the sensory characteristics of broiler chicken meat. In general, it can be concluded that L-carnitine can be used as a dietary supplement on the health of broiler chickens without any negative effect on growth performance.

Keywords: Dietary supplements; fat burning; triglycerides, cholesterol, L-carnitine

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INTRODUCTION

With the spread of various nutrition-caused diseases, producing food and meat consistent with human health has become increasingly important and this has limited the consumption of fatty-rich food such as high-fat chicken meat. Besides, increased fat accumulation in chickens is considered as waste in slaughterhouse operations, and manufacturers always seek fat removal strategies to reduce the cost of production and to produce healthy chickens (Golzae Adabi et al., 2011). In this regard, changes in the rate and nutrient level of the diet and the use of fat burning supplements, such as medicinal plants were found to be effective in reducing fat. Fatty chemicals used to control fat in humans have been introduced to address this problem.

Today, the use of L-carnitine, as a component of the essential substances in body to increase energy efficiency and dietary fat, as well as reduce the accumulation of abdominal fat and plasma, is increasing in the food industry.

L-carnitine is an anti-fatty drug for controlling fat in humans and its use in poultry feed including broilers has been reported to be effective in controlling lipid and ventricular fat (Golzae Adabi et al., 2011; Hrncar et al., 2015; Khatibjoo et al., 2016).

L-carnitine is made in the liver of humans and animals and then transferred to muscle tissue. Most L-carnitine is stored in skeletal and heart muscle, and is a mixture of L-carnitine synthesized in the body and L-carnitine absorbed from the diet (Taklimi et al., 2015). The use of L-carnitine in poultry feed helps increase energy efficiency so that poultry can more quickly and easily obtain the energy they need from dietary lipids. Positive effect of L-carnitine on reducing feed intake (Khatibjoo et al., 2016; Mirzapor Sarab et al., 2016), live weight gain (Kidd et al., 2009), increased final weight, improved feed conversion ratio, improved carcass characteristics (Hrncar et al., 2015) and reduced abdominal fat (Babazadeh Aghdam et al., 2015) have been reported for different poultry. L-carnitine also increases the antioxidant and immune capacity of poultry and prevents cardiovascular disease, pulmonary hypertension and ascites in poultry by affecting nitric oxide production and recovery of myocardial energy reserve (Buyse et al., 2007; Xue et al., 2007; Khajali et al., 2011). The effect of L-carnitine on broiler chickens will be the subject of this review.

L-CARNITINE

L-carnitine (L-Trimethyl-3-hydroxyamino-butanate) is a pseudo-vitamin and deformed amino acid, first isolated in 1905 from muscle tissues, and its structure was identified in 1927.

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. The synthesis of L-carnitine in the body is a multi-stage process and is performed by adding a hydroxyl group to a third carbon lysine in various organs such as mitochondria, kidneys, liver, brain and muscles. The complete process for the synthesis of L-carnitine is presented in Figure 1.

L-carnitine has two main roles in the body, including facilitating the entry of long-chain fatty acids into mitochondria, as well as the release of short and medium-chain fatty acids from the mitochondria. In addition to the roles such as eliminating the toxic effects of acyl groups from cells, adjusting the ratio of coenzyme A to the acyl-coenzyme A in cytosol and mitochondria, gluconeogenesis, are also reported for L-carnitine (Corduk et al., 2007; Parsaeimehr et al., 2014a).

L-carnitine is a drug for lowering plasma lipids that reduces cholesterol, triglycerides, free fatty acids, phospholipids, and low-density lipoproteins and increases high-density lipoprotein. In addition to the role of L-carnitine in the oxidation of fatty acids, its role in carbohydrate metabolism has also been reported (Rajasekar and Anuradha 2007). Today, the use of L-carnitine supplementation is increasing as part of the body's essential nutrients to increase the energy and fat intake of food and to reduce the accumulation of ventricular and plasma fat.

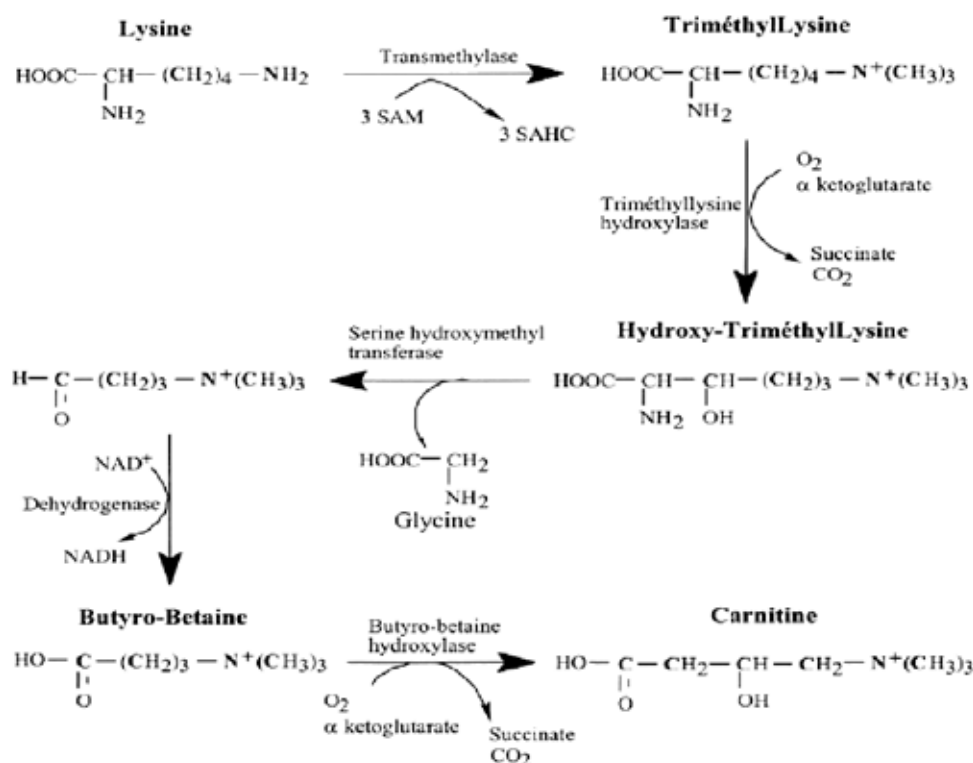


Figure 1. Biosynthesis of L-carnitine (Arslan, 2006).

THE NECESSITY OF USING L-CARNITINE IN POULTRY DIET

L-carnitine is an essential and water-soluble substance naturally existing in plants, animals and microorganisms, however, the amount of L-carnitine in herbs and plants is lower than that of the animals, and since the poultry diet is mostly formed of feed of plant origin, using the supplementation of L-carnitine in a diet or drinking water is necessary to achieve optimal performance (Taklimi et al. 2015). It should be noted that the normal amount of L-carnitine per kilogram of poultry feed is 2 to 5 milligrams and an average of 25 to 50 milligrams per day (Mirzapor Sarab et al., 2016).

L-carnitine is involved in many metabolic processes, such as lipid metabolism, energy liberation, improved production efficiency, immune enhancement, etc. (Khatibjoo et al., 2016; Mirzapor Sarab et al., 2016). This substance prevents lipogenesis and increases the burning rate of fat. Burning of fatty acids happens in body cells and energy production occurs in the mitochondria; the mitochondrial membrane is infused; therefore, it is required to have a carrier to transport fatty acids to the oxidation place mitochondria, that L-carnitine acts as a carrier and by the

transport of long-chain fatty acids into mitochondria increases the oxidation of fatty acids and facilitates the production of energy (Kheirkhah et al., 2009).

The use of L-carnitine in poultry feed helps increase the energy efficiency of poultry so that poultry can quickly and easily absorb the energy needed from the dietary lipids. Besides, the use of L-carnitine causes a significant reduction in feed intake in poultry (Khatibjoo et al., 2016; Mirzapor Sarab et al., 2016). Several studies have shown that sufficient amounts of L-carnitine in poultry diets with different levels and sources of fat, can be appropriate to optimal yield, increased feed efficiency and increased economic returns (Parsaeimehr et al. 2014b; Abedpour et al. 2017; Swarna et al. 2018).

Effect of L-carnitine cofactors in broiler diet

Carnitine is synthesized in different parts of the body in living creatures. For example, the synthesis of carnitine in the liver of all mammals, muscles of sheep, brain and kidneys of humans and all the cats occurs through methioninolysin. The synthesis of carnitine in the body of different living organisms requires enzymes as well as cofactors such as ascorbic acid, niacin, pyridoxine and iron oxide. Researchers

believe that poultry and mammals can produce carnitine if they are sufficiently present in the diet (Ghoreyshi et al., 2019).

The use of lysine and methionine amino acids in the diet was effective in supplying carnitine in poultry. Celik and Ozturkcan (2003) examined the effect of ascorbic acid, a precursor of carnitine synthesis in the body, on broiler chickens under thermal stress. In this study, the use of carnitine and ascorbic acid in normal conditions significantly reduced the growth of broiler chickens. In another study, the use of carnitine alone and in combination with niacin, which is a co-factor of carnitine production in the body, improved the performance of broiler chicks in the early stages of growth (Celik et al., 2003).

EFFECT OF L-CARNITINE ON THE PERFORMANCE OF BROILER CHICKENS

Kidd et al. (2009) reported that supplementation of L-carnitine supplementation in broiler diets does not have a significant effect on yield, but thigh and body weight gain is increased with 40 mg/kg of L-carnitine. Hrncar et al. (2015) used L-carnitine (1 ml/1.2 l) in drinking water in Ross 308 broiler chickens. In that study, the application of L-carnitine increased final weight and improved feed conversion ratio. Kamal et al. (2019) stated that consumption of L-carnitine in the diet of broilers increases live weight, final weight and reduces feed intake and feed conversion ratio. Ghoreyshi et al. (2019) stated that the use of 15% L-carnitine + 30% methionine + 30% lysine throughout the whole period reduces feed intake compared to the control, but the highest weight gain was achieved with the use of 15% of the above mentioned compounds.

Tufarelli et al. (2020) found that L-carnitine consumption did not have a significant effect on live weight of broiler chickens in the starter, grower, and finisher periods, but feed intake increased with the use of L-carnitine during the starter period. The feed conversion ratio increased with the use of L-carnitine in the starter period and decreased in the final period by consuming 50 mg/kg; feed intake was also improved with the application of different levels of L-carnitine in broiler chickens in different experiments (Celik et al., 2003).

It is stated that consumption of L-carnitine increases the weight of the chickens during the first three weeks of growth, but did not affect the weight

of the chickens in the final three weeks (Celik et al., 2003). Researchers have found that body weight gain in broiler chickens by the use of L-carnitine in the diet is due to the role of L-carnitine in increasing the oxidation of long-chain fatty acids and increasing the level of acetyl coenzyme A in mitochondria, which increases the use by chickens of the diet protein (Mirzapor Sarab et al., 2016).

Improvement of the nutritional conversion ratio in broiler chickens and laying hens with the combined use of L-carnitine and vitamin C was reported (Celik and Ozturkcan, 2003; Hassan et al., 2011). Xu et al. (2003) reported that L-carnitine had no significant effect on functional traits (live weight, feed intake and feed conversion ratio) at 0, 25, 50, 75 and 100 mg/kg levels. Khajali and Khajali (2014) used 200 mg/kg of L-carnitine in broiler diets; the results showed that the application of L-carnitine had no significant effect on body weight, feed intake and feed conversion ratio.

Wang et al. (2013) investigated the effect of L-carnitine supplemented diet in low-temperature conditions on broiler chickens Ross 308 strains. The results showed that the performance of chicken was not affected by L-carnitine, but the susceptibility to ascites was greatly reduced. Parsaeimehr et al. (2013) used a diet containing plant and animal fat with L-carnitine. The results of that study showed that the addition of L-carnitine to a diet containing animal fat increases the weight of the Ross 308 chickens during the growth and the whole period. Also, feed intake significantly decreased with this treatment. Adding L-carnitine to the diet reduced the feed conversion rate at the finisher period.

In a study, 0, 150, 300, 450 and 600 mg/kg of L-carnitine was used in the base diet of Ross 308 male broiler chickens; the results showed that adding L-carnitine up to 600 mg/kg had no effect on weight gain of the initial period (1-21 days), but, it was effective on the weight of chicken during the growth period and the whole period. There was no significant difference between the treatments in feed intake during the growth period and the whole period. Also, the addition of L-carnitine in the diet did not have a significant effect on the feed conversion ratio in three periods of starter, grower, and finisher (Parsaeimehr et al., 2014b).

Shirali et al. (2015) examined the effects of different levels of vitamin E and L-carnitine in the diet of chickens under thermal stress and reported that the

interaction of vitamin E and L-carnitine had a significant effect on yield, feed intake, feed conversion ratio of chickens during the breeding season. Treatment of 100 mg/kg vitamin E with 100 mg/kg L-carnitine had the highest live weight during the starter period (1-21 days). However, during the starter period and the whole period, the treatments did not significantly affect the weight gain of chickens.

Farrokhyan et al. (2014) examined the effect of L-carnitine (0, 150 and 300 mg/kg) and gemfibrozil (0, 1 and 2 g/kg) on broiler diets. The results showed that application of the treatment without gemfibrozil and with 300 mg/kg of l-carnitine, yielded the highest live weight. Also, the highest feed intake during the 1-6 week period was achieved with 300 mg/kg of L-carnitine without gemfibrozil whereas the lowest was achieved with a diet supplemented with 1 g/kg of gemfibrozil with 300 mg/kg of L-carnitine. The lowest feed conversion ratio was observed in diets supplemented with 1 g/kg gemfibrozil with 300 mg/kg of L-carnitine and a diet supplemented with 300 mg/kg of L-carnitine with no gemfibrozil added.

Rajabzadeh-Nesvan et al. (2013) reported the effect of L-carnitine (0 and 125 mg/kg) on the diets containing different sources of fat (soybean oil, animal fat, and their mixture) on Ross 308 broiler chickens. The results showed that different sources of fat and L-carnitine had no significant effect on chicken yield. The effect of L-carnitine on the performance of chickens was not significant, but the use of L-carnitine reduced the feed conversion ratio, increased feed intake and increased weight of chickens compared to the control.

Arslan and Tufan (2018) investigated the effect of a diet supplemented with oligosaccharide chitosan and L-carnitine on broiler chickens and showed that there was no significant difference between diets on body weight, feed intake and feed conversion ratio. Rezaei et al. (2007) indicated that the application of fat (1, 3 and 5%) and 2 levels of L-carnitine (0 and 250 mg/kg) in the diet of broiler chickens reduced feed conversion ratio and increased feed intake.

Taraz and Dastar (2008) showed that the application of 125 mg/kg of L-carnitine in a diet containing various protein levels would increase body weight and carcass performance of cookable broiler chickens. Kheirkhah et al. (2009) reported that L-carnitine had no effect on feed conversion ratio, but reduced feed intake and increased weight of broiler chickens.

Darsi Arani et al. (2010) reported that application of 50 mg/kg of L-carnitine in a diet containing three levels of crude protein (21, 19.5 and 18%) did not affect body weight, feed intake or feed conversion ratio.

Akbari Azad et al. (2010) reported that the application of 375 mg/kg of L-carnitine in the diet significantly reduced consumption and weight gain and thus increasing European production efficiency. Research results showed that broiler chickens fed diets supplemented with L-carnitine and butyric acid were not significantly different in terms of feed intake, weight gain and feed conversion ratio (Norreh et al., 2015).

Jalali et al. (2015) investigated the effects of L-carnitine in a diet of soybean oil and sunflower oil on broiler chickens, the results showed that soybean oil with 120 mg/kg of L-carnitine significantly improved live weight and feed conversion ratio in the grower and finisher stages. Fallah et al. (2016) showed that adding terbutaline and L-carnitine to the diet increased weight gain compared to the control group. Feed intake and feed conversion ratio also significantly improved with the use of these substances in the diet.

Application of L-carnitine in drinking water in broiler chickens improved performance (Nouboukpo et al., 2010). Mehdizadeh Taklimi et al. (2015) evaluated the effect of L-carnitine (0, 400, 600 and 800 mg/kg) as liquid and powder on the performance of broiler chickens and reported that chickens from the diet containing 600 mg L-carnitine per kg of the diet were more likely to grow faster in grower period than in the other experimental groups. The highest live weight of the entire course was also 800 mg/kg of L-carnitine. The researchers stated that the L-carnitine type (powder and liquid) did not affect body weight. Feed intakes were significantly higher in chickens fed the 400 mg/kg of the L-carnitine diet. The most suitable feed conversion ratio was observed in the growth stage (1- 21 days) as well as the entire experimental period (1-42 days) in a diet containing 800 mg/kg of L-carnitine.

Rehman et al. (2017) used vitamin E (250 mg/kg), ginger (2 g/kg) and l-carnitine (500 mg/kg) in the diet of Hubbard and Cobb broiler chickens exposed to heat stress. The results of this study showed that feed intake and feed conversion ratio increased with the application of L-carnitine compared to other treatments. Murali et al. (2013) used 2 levels of L-carnitine (0 and 900 mg/kg) in the base diet of Van Cobb

chickens. The results of this study showed that growth performance did not change under the influence of L-carnitine.

Khatibjoo et al. (2016) investigated the effects of L-carnitine and butyric acid on 192 broiler chickens of Ross 308 and reported that the chickens fed by a diet containing 125 mg/kg of L-carnitine and 2 g/kg of butyric acid had a lower feed intake and a better feed conversion ratio relative to the control group. In the study by Murali et al. (2015), the application of 900 mg/kg of L-carnitine in the diet of broiler chickens strain Cobb did not have any effect on yield. Celik and Ozturkcan (2003) used two levels of L-carnitine (0 and 50 mg/kg) and 2 levels of ascorbic acid (0 and 50 mg/kg) in drinking water of broiler chickens under different thermal regimes. The results showed that live chicken weight significantly improved with the use of L-carnitine, ascorbic acid and L-carnitine plus ascorbic acid under high-temperature conditions. The effect of L-carnitine on feed conversion ratio and water and food consumption was not significant.

Application of 300 mg/kg of L-carnitine to broiler

diets caused weight gain in the final course and the whole period. Feed conversion ratio in chicken fed 200 and 300 mg/kg L-carnitine was the lowest in the finisher period (Babazadeh Aghdam et al., 2015). Parsaeimehr et al. (2014a) reported that a complementary diet of L-carnitine and 5% animal fat improved body weight and feed conversion ratio in broiler chickens.

The conclusion that can be drawn from this review is that the application of L-carnitine in base diets and complemented with different levels of fat did not have a negative effect on the performance of broiler chickens. Although in some studies, the effect of L-carnitine on body weight gain, feed intake and feed conversion ratio were positive; but in many cases, L-carnitine did not have a significant effect compared to control.

In general, it can be concluded that the use of L-carnitine supplementation in diets with different levels of plant and/or animal fat was found to be beneficial for achieving optimal performance, however, it is not recommended if the purpose is to improve performance only.

Table 1. Effect of L-carnitine on the performance of broiler chickens

Reference	Applied treatment	Effects
Kidd et al., 2009	40 mg/kg	Live weight increase
Hrncar et al., 2015	1 ml /1.2 L	Live weight increase and improved feed conversion ratio
Celik et al., 2003	50 mg/kg	Improved feed intake and increased weight in the first three grower weeks
Xu et al., 2003	25, 50, 75, 100 mg/kg	No significant effect on performance traits
Khajali and Khajali, 2014	200 mg/kg	No significant effect on performance traits
Wang et al., 2013	100 mg/kg	No significant effect on performance traits and positive effect on ascites reduction
Parsaeimehr et al., 2013	150, 300, 450 , 600 mg/kg	Weight increase in grower period and whole period decreased feed intake and decreased feed conversion ratio in the finisher period
Shirali et al., 2015	100 mg/kg	No significant effect on performance traits
Rajabzadeh-Nesvan et al., 2013	125 mg/kg	Increased feed intake, weight gain increase, and reduced feed conversion ratio
Arsalan and Tufan, 2018	100 mg/kg	No significant effect on performance traits
Rezaei et al., 2007	250 mg/kg	Increased feed intake and reduced feed conversion ratio
Taraz and Dastar, 2008	125 mg/kg	Bodyweight increase and carcass cooking performance
Kheirkhah et al., 2009	100 , 200 mg/kg	Weight increase, feed intake decrease and no significant effect on the feed conversion ratio
DarsiArani et al., 2010	50 mg/kg	No significant effect on performance traits
Akbari Azad et al., 2010	375 mg/kg	Increasing weight and improving European production efficiency, decreasing feed consumption
Norreh et al., 2015	125, 250 mg/kg	No significant effect on performance traits

Jalali et al., 2015	120 mg/kg	Improving live weight and feed conversion ratio in the grower and finisher periods
Fallah et al., 2016	100 mg/kg	Live weight increase, improved feed consumption and feed conversion ratio
Nouboukpo et al., 2010	500, 1000 mg/kg	Improving performance
MehdizadehTaklimi et al., 2015	400, 600, 800 mg/kg	Increased live weight, feed intake and improved feed conversion ratio
Rehman et al., 2017	500 mg/kg	Increased feed intake and improved feed conversion ratio
Murali et al., 2013	900 mg/kg	No significant effect on performance traits
Khatibjoo et al., 2016	125 mg/kg+2 g Butyric acid	Decreased feed intake and improved feed conversion ratio
Murali et al., 2015	900 mg/kg	No significant effect on performance traits
Celik and Ozturkcan, 2003	500 mg/kg	Improved live weight, no significant effect on feed conversion ratio and water and feed consumption
BabazadehAghdam et al., 2015	200, 300 mg/kg	Increased live weight and decreased feed conversion ratio
Parsaeimehr et al., 2014a	300 mg/kg	Improved live weight and feed conversion ratio
Corduk et al., 2007	100 mg/kg	No effect on weight increase
Parsaeimehr et al., 2014b	150, 300, 450, 600 mg/kg	No effect on performance, feed intake and conversion ratio

Effect of L-carnitine on carcass characteristics of broiler chickens

Ghoreyshi et al. (2019) stated that the use of L-carnitine, lysine and methionine had no significant effect on body weight, breast, heart, liver, gizzard, pancreas and abdominal fat, but significantly reduced thigh, neck, duodenum, jejunum and ileum weight. Islam and Ouda (2020) stated that consuming L-carnitine increases carcass weight but does not have a significant effect on the weight of heart, gizzard and abdominal fat of broilers. Fujimoto et al. (2020) showed that L-carnitine consumption has no significant effect on the carcass characteristics of broilers.

Murali et al. (2015) examined the effect of dietary supplement with L-carnitine (900 mg/kg) and animal fat (5%) on the carcass characteristics of broiler chickens. The results showed that the least abdominal fat was achieved in chicken treated with L-carnitine supplement. In that study, it was found that L-carnitine had no effect on body weight, full carcass weight, empty carcass weight, carcass yield, meat characteristics and internal organs weight.

Tufarelli et al. (2020) reported that the use of 100 and 50 mg/kg L-carnitine in the diet of broilers increased breast weight but had no significant effect on heart weight, pancreas, gizzard and abdominal fat. Xu et al. (2003) stated that the effect of 25 mg/L L-carnitine was useful in reducing the abdominal fat of broil-

ers. However, there are also some reports stating that L-carnitine has no effect on reducing the abdominal fat of broilers (Tufarelli et al., 2020).

Babazadeh Aghdam et al. (2015) reported that consuming 300 mg/kg of L-carnitine in the diet reduced the fat content of the abdominal area of the broiler chickens with ROSS strain. However, different levels of L-carnitine (100, 200 and 300 mg/kg) had no significant effect on carcass characteristics. In the study of Xu et al. (2003), L-carnitine had a positive effect on foot muscle function, breast muscles and abdominal fat loss. Hrncar et al. (2015) reported that the addition of L-carnitine to broiler chicken diet had a positive but non-significant effect on abdominal fat, heart, liver and gizzard. Rezaei et al. (2007) stated that the addition of 250 mg/kg of L-carnitine to the diet of broiler chickens ROSS strain does not affect carcass characteristics.

In a study by Celik et al., (2003), it was found that supplementation of the diet of broiler chickens with L-carnitine had no significant effect on carcass weight and yield and ventricular fat. In the study of Daskiran and Teeter (2001), the use of L-carnitine had no significant effect on carcass yield and ventricular fat content, but Xu et al. (2003) reported increased breast muscles in male broiler chickens using 50 and 75 mg/kg of L-carnitine in the diet.

The effect of 200 mg/kg of L-carnitine in broil-

er chicken diet did not affect carcass, but the amount of ventricular fat significantly decreased compared to the control (Khajali and Khajali, 2014). The results showed that using supplementation of L-carnitine in the base diet of Ross 308 broiler chickens increases the relative weight of the breast and thighs (Parsaeimehr et al., 2014b). Also, the use of L-carnitine caused a significant decrease in abdominal cavity fat at 42 days of age (Parsaeimehr et al., 2014b). The use of L-carnitine did not have a significant effect on the relative weight of the bursa, spleen, heart and liver of broiler chickens (Parsaeimehr et al., 2014b).

In a study, vitamin E (0, 100 and 200 mg/kg) and L-carnitine (0, 50 and 100 mg/kg) were used in broiler diets. Carcass analysis showed that the effect of treatments on the percentage of breast, thigh, liver, gizzard and pancreas was not significant. However, the use of L-carnitine significantly reduced ventricular fat. The interaction of vitamin E and L-carnitine was also effective in reducing the ventricular fat in broiler chickens (Shirali et al., 2015). Evaluation of carcass characteristics of broiler chickens fed diets supplemented with different levels of L-carnitine and gemfibrozil showed that with the use of L-carnitine alone, the weight of carcasses was reduced compared to the control. The heaviest weights of full and empty carcasses were obtained using 300 and 150 mg/kg of L-carnitine plus 2 grams per kilogram of gemfibrozil, respectively. The interaction of L-carnitine and gemfibrozil increased weights of breast, wings, heart, liver and decreased ventricular fat. But there was no effect on the thigh weight (Farrokhyan et al., 2014).

Study of different levels of L-carnitine supplementation and fat source on the percentage of carcass components in broiler chickens at the age of 42 days showed that using L-carnitine had no significant effect on heart, liver, breast and thigh weights. But significantly reduced abdominal fat. The lowest abdominal fat was obtained in the treatment in which soy oil and 125 mg/kg L-carnitine were combined. L-carnitine was also effective in reducing fat in thigh, breast and full carcass (Rajabzadeh-Nesvan et al., 2013).

The study of the effect of butyric acid and L-carnitine on carcass characteristics of broiler chickens showed that the interaction of treatments on abdominal fat percentage and carcass fat percentage was not significant. Application of 250 mg/kg L-carnitine in the diet improved the percentage of the breast in chickens (Khatibjoo et al., 2016). The use of chitosan oligosaccharide and L-carnitine in broiler diets had

no significant effect on carcass weight, nor on breast, wing and leg to carcass weight ratios. The percentage of ventricular fat in diets with chitosan oligosaccharide, L-carnitine and L-carnitine plus chitosan oligosaccharide was less than in a control diet. The use of L-carnitine and L-carnitine + chitosan oligosaccharide reduced the weight of the liver relative to the control and chitosan oligosaccharide diets (Arslan and Tufan, 2018).

Application of different levels of fat and L-carnitine in broiler chicken diets increased breast meat and liver weight but decreased ventricular and fetal fat (Rezaei et al., 2007). Research results showed that application of 50 mg/kg L-carnitine in a diet containing various levels of crude protein significantly reduces fat in thigh muscles, the full carcass as well as abdominal fat (Darsi Arani et al., 2010). The addition of terbutaline and L-carnitine in broiler diet significantly increased the weights of heart, gizzards, spleen, and the bursa of fabricius, and reduced the amount of abdominal fat (Fallah et al., 2016).

Mehdizadeh Taklimi et al. (2015) reported that mean crude protein and carcass fat content was not affected by different levels of L-carnitine in the diet, but with the use of L-carnitine powder in the diet, the amount of carcass ash significantly decreased. Using L-carnitine, broiler chicken carcass fat decreased compared to control and treatment of vitamin E and ginger (Rehman et al., 2017). Khadem et al. (2006) reported that the use of L-carnitine induced a significant reduction in chicken abdominal fat. A similar reduction of abdominal fat by the use of L-carnitine in broiler diets was also reported by Parsaeimehr et al. (2014a).

Jafari Golrokh et al. (2016) showed that the use of L-carnitine and atorvastatin in the diet of broiler chickens improved the quality of carcasses by affecting the amount and distribution of muscle fats, carcass traits and blood parameters. In that study, L-carnitine at both levels of 150 and 300 mg/kg increased the weights of empty body and full carcass, breast, thigh, gizzard, liver and heart as compared to the control.

According to the above review, it can be concluded that L-carnitine is effective in reducing ventricular fat and fat in different carcass parts (thigh and breast) organs and significantly decreases ventricular fat in broiler chickens. But in most cases, there was no significant effect on weight and yield of internal organs and carcasses.

Table 2. Effect of L-carnitine on carcass characteristics of broiler chickens

Reference	Applied treatment	Effects
Murali et al., 2015	900 mg/kg	Positive effect on reducing abdominal fat and no effect on carcass weight and internal organs
Xu et al., 2003	25, 50 mg/kg	Reducing abdominal fat, improving the performance of leg and breast muscles
BabazadehAghdam et al., 2015	300 mg/kg	Reduced abdominal fat and no effect on carcass characteristics
Hrncar et al., 2015	1 mL/1.2 L	Positive effect on abdominal fat, weights of heart, liver and gizzard
Rezaei et al., 2007	250 mg/kg	No significant effect on carcass characteristics
Celik et al., 2003	50 mg/kg	No significant effect on carcass weight and weight of abdominal fat
Daskiran and Teeter, 2001	150 mg/kg	No significant effect on carcass traits and content of abdominal fat
Khajali and Khajali, 2014	200 mg/kg	No significant effect on carcass and breast, positive effect on abdominal fat
Parsaeimehr et al., 2014b	300 mg/kg	Increasing the relative weight of carcass, thigh and significant decrease of abdominal cavity fat, no effect on the weight of bursa of Fabricius, spleen, heart and liver
Shirali et al., 2015	50 , 100 mg/kg	No effect on the percentage of breast, thigh, liver, gizzard, pancreas and significant decrease of abdominal fat
Farrokhyan et al., 2011	150, 300 mg/kg L-carnitine + 2 g / kgGemfibrozil	Increased weights of carcass and internal organs
Rajabzadeh-Nesvan et al., 2013	125 mg/kg	No significant effect on the weight of internal organs and a positive effect on reducing carcass fat
Khatibjoo et al., 2016	250 mg/kg	Improving breast percentage and no significant effect on abdominal fat
Arslan and Tufan, 2018	100 mg/kg L-carnitine+ 100 mg/kgChitosan Oligosaccharide	Positive effect on carcass weight and reducing abdominal fat
Rezaei et al., 2007	250 mg/kg	Increasedbreast meat and liver weight and reduced abdominal fat and fat of breast meat
DarsiArani et al., 2010	50 mg/kg	Reduced-fat in thigh and carcass and also abdominal fat
Fallah et al., 2016	10 mg/kg + 100 mg/ kgterbutaline	Positive effect on increasing weights of heart, gizzard, spleen, bursa of Fabricius and reducing abdominal fat
MehdizadehTaklimi et al., 2015	400, 600, 800 mg/kg	Reduced level of carcass ash, no significant effect on mean crude protein orcarcass fat content
Rehman et al., 2017	500 mg/kg	Reduced abdominal fat
Khadem et al., 2006	50 mg/kg	Reduced abdominal fat
Parsaeimehr et al., 2014a	300 mg/kg	Reduced abdominal fat
JafariGolrokh et al., 2016	150, 200 mg/kg	Positive effect on improving carcass quality
Miah et al., 2004	50 mg/kg	Reduced abdominal fat
Kheirkhah et al., 2009	100, 200 mg/kg	No effect on carcass traits
Xu et al., 2003	50 , 75 mg/kg	Increased weight of breast muscle and reducedabdominal fat
Daskiran andTeeter, 2001	150 mg/kg	No effect on carcass yield and abdominal fat
Oladele et al., 2011	60 mg/kg	Increased carcass yield and reduced abdominal fat
Zhang et al., 2010	300, 600, 900 mg/kg	Reduced abdominal fat
Kheiri et al., 2011	60, 120 mg/kg	Reduced abdominal fat
Ardekani et al., 2012	50 mg/kg	No significant effect on abdominal fat
Celik and Ozturkcan, 2003	500 mg/kg	No effect on the weight of internal carcass organs

Effect of L-carnitine on the immunity of broiler chickens

The effect of L-carnitine on enzymatic activity in subcutaneous fat in male broiler chickens showed that hormone-sensitive lipase (HSL)-activity was higher at 50 and 75 mg/kg L-carnitine levels than at 0, 25 and 100 mg/kg L-Carnitine levels. The activity of lipoprotein lipase (LPL), glucose-6-phosphate dehydrogenase, malic dehydrogenase and iso-citrate dehydrogenase decreased with the use of L-carnitine. The activity of carnitine-palmityl transferase-I by increasing the level of carnitine in the diet decreased significantly (Xu et al., 2003).

The use of L-carnitine in broiler diets affects the function of the immune system. Mirzapor Sarab et al. (2016) found that the use of L-carnitine in broiler chicken diets does not affect antibody production against Newcastle and Sheep red blood cells (SRBC). Research results showed that heterophil to lymphocyte ratio in broiler chickens fed diets supplemented with L-carnitine had no significant difference compared to the control (Khajali and Khajali, 2014).

In a study, it was stated that the effect of different levels of vitamin E and L-carnitine was not significant on the relative weight of the immune organs (thymus, spleen, and bursa of fabricius). The application of 50 mg/kg of L-carnitine increased the antibody titer against SRBC during the initial response (Shirali et al., 2015). Akbari Azad et al. (2010) reported that the application of 375 mg/kg of L-carnitine increased the antibody titer against Newcastle disease and influenza. Also, this treatment had a positive effect on the improvement of the population of white and red blood cells, hemoglobin, hematocrit, and triglyceride in broiler chickens.

Research results of Khatibjoo et al. (2016) showed that the application of 0.025% L-carnitine and 1.5% garlic powder to broiler chicken diet did not affect cellular and humoral immunity but increased the immunity through blood cells and improved the body defense system in broiler chickens. Norreh et al. (2015) reported that the use of L-carnitine and butyric acid in the diet increased lymphocyte percentages. Also, the initial IgG titre (31 days) in response to the sheep's red blood cell was higher in the chicken fed a diet containing 125 mg/kg of L-carnitine compared to the control.

Jalali et al. (2015) found that the use of supplementation of L-carnitine in a diet of broiler chickens

containing soybean oil would increase antibody titer against Newcastle virus. Researchers reported an increase of flu and Newcastle antibody titers in the 18th and 28th day of life using Terbutaline and L-carnitine in the diet of Ross 308 broiler chickens (Fallah et al., 2016). Rehman et al. (2017) investigated the effect of vitamin E (250 mg/kg), ginger (2 g/kg) and L-carnitine (500 mg/kg) on the antibody titer against infectious bursa IBD and Geometric mean titer (GMT) of broiler chickens under thermal stress. The results showed that all treatments increased titers on days 21, 28, 35, and 42. But vitamin E was more effective in these traits.

Parsaeimehr et al. (2014a) reported that the use of L-carnitine had a significant effect on Newcastle antibody titer at 32 days of age but had no effect on Newcastle-antibody titer at 42 days of age. Researchers investigating the effects of L-carnitine (0 and 200 mg/kg), coenzyme Q10 (0 and 40 mg/kg), and ractopamine (0 and 10 mg/kg) in a factorial experiment on chicken Ross 308 male broiler showed that the addition of coenzyme Q10 and L-carnitine in the diet of broiler chickens has a positive effect on immune response (Asadi et al., 2016).

The results of a research showed that using the mixture of L-carnitine, lysine and methionine in the basic diet of broilers did not have a significant effect on antibody titers against sheep red blood cells, bronchitis and weight of the bursa of fabricius and spleen, but increased antibody titers against Newcastle (Ghoreyshi et al., 2019).

In most studies, the use of L-carnitine in the diets of broiler chickens led to improvements in the immune system. In some studies, the effect of L-carnitine on control of the immune system in broiler chickens was not statistically significant. Overall, L-carnitine can be effective in improving immunity, increasing resistance to diseases and decreasing ascites in broiler chickens.

Table 3. Effect of L-carnitine on the immunity of broiler chickens

Reference	Applied treatment	Effects
Xu et al., 2003	25, 50, 75, 100 mg/kg	Increased activity of hormone-sensitive lipase (HSL), decreased Lipoprotein lipase (LPL) activity, glucose-6-phosphate dehydrogenase, malic hydrogenase, iso-citrate dehydrogenase and carnitine palmitoyltransferase I
MirzaporSarab et al., 2016	50, 100 mg/kg	No significant effect on the production of antibody against SRBC
Khajali and Khajali, 2014	200 mg/kg	No significant effect on heterophil to lymphocyte ratio
Shirali et al., 2015	50 mg/kg	Increased antibody titer against SRBC, no significant effect on the relative weight of immune organs (thymus, spleen and bursa of Fabricius).
Akbari Azad et al., 2010	375 mg/kg	Increasing antibody titers against Newcastle disease and influenza and positive effect on white and red blood cells, hemoglobin, hematocrit and triglyceride
Khatibjoo et al., 2016	0.025 %	No effect on cellular and humoral immunity and increased immunity through blood cells and improvement of the immune system.
Norreh et al., 2015	125 mg/kg	Increased percentage of lymphocytes and primary IgG titers
Jalali et al., 2015	120 mg/kg	Increased antibody titer against Newcastle virus
Fallah et al., 2016	100 mg/kg l-carnitine + 100 mg/kg terbutaline	Increase in antibody titers against Newcastle and Influenza viruses during the 18th and 28th day of life
Rehman et al., 2017	500 mg/kg	Increased antibody titers against IBD and GMT
Parsaeimehr et al., 2014a	300 mg/kg	Significant effect on Newcastle disease antibody titer at 32 days of age but no effect at 42 days
Asadi et al., 2016	200 mg/kg	Positive effect on the immune system
Azadmanesh and Jahanian, 2014	100 mg/kg	No effect on antibody titers against Newcastle disease and bronchitis
Kheirkhah et al., 2009	100, 200 mg/kg	No effect on the production of antibodies against SRBC
Golzaradabi et al., 2011	100 mg/kg	Increase in antibody titers against SRBC and Newcastle disease. Weight gain of thymus, spleen, and bursa of Fabricius
Deng et al., 2006	1000 mg/kg	Increased thymus weight, increased antibody level against SRBC

Effect of L-carnitine on blood parameters of broiler chickens

Xu et al. (2003) showed that the application of (0, 25, 50, 75 and 100 mg/kg) L-carnitine, especially 50 mg/kg, reduced serum triglyceride in broiler chickens. Levels of serum-free fatty acids increased significantly with the use of L-carnitine compared to the control. L-carnitine supplementation in the diet of broiler chickens containing 1, 3 and 5% fat significantly decreased triglyceride, cholesterol and VLDL in blood serum (Rezaei et al., 2007). In the study of

Hassan et al. (2011), they found that elevated levels of L-carnitine had a greater effect on cholesterol levels. It is showed that triglyceride levels of chicken fed L-carnitine decreased compared to the control, but the concentration of cholesterol, phospholipids and serum lipoprotein was not affected by L-carnitine. The reduction in triglyceride content of blood serum with the use of L-carnitine was reported by Zhang et al. (2010) and the reason was increased catabolism of fatty acids by L-carnitine.

Tufarelli et al. (2020) stated that the use of L-carnitine along with 20% lysine-methionine reduced uric acid and increased total cholesterol in broilers. The effect of L-carnitine consumption had no significant effect on glucose and triglyceride levels.

The reduction of serum triglyceride and very low-density lipoproteins (VLDL) was reported by Xu et al. (2003).

Kamal et al. (2019) reported that L-carnitine does not have a significant effect on blood parameters and liver enzymes. The results of Islam and Ouda (2020) showed that by consuming L-carnitine in the diet of broilers, the total protein content increases and the amount of cholesterol, triglycerides, LDL and blood glucose decreases. Abouzed et al. (2019) stated that the consumption of L-carnitine in the drinking water of broilers does not have a significant effect on blood parameters and digestive enzymes.

Application of 200 mg/kg of L-carnitine in the approved Cobb 500 strain reduced the concentration of malondialdehyde in plasma and hematocrit (PCV) and increased plasma nitric oxide (Khajali and Khajali, 2014). The results showed that the application of 100 mg/kg L-carnitine reduced plasma malondialdehyde (MDA) levels in broiler chickens (Tan et al., 2008). In Yousefi et al. (2013), plasma MDA concentration also decreased significantly with the use of a diet containing 50 and 150 mg/kg of L-carnitine. Research results showed that chickens fed with L-carnitine had significantly lower red blood cells (RBC), hemoglobin (HGB) and hematocrit (HCT) at 42 days of age. L-carnitine also significantly reduced MDA levels from 21 to 35 days of age, and increased superoxide dismutase (SOD) and Gsh-Px activity at 21 to 42 days of age. The use of L-carnitine significantly reduced serum triglyceride, glucose, uric acid and a significant increase in total serum protein and globulin content was observed (Wang et al., 2013).

Zhang et al. (2010) also reported a significant decrease in serum cholesterol and triglyceride levels with increasing levels of L-carnitine in the diet. The use of L-carnitine reduced the level of triglyceride and increased the level of serum cholesterol (Kheiri et al., 2011). Parsaeimehr et al. (2013) investigated the use of L-carnitine and a diet containing animal and plant fats for broiler chickens Ross strain. The results showed that the use of L-carnitine had no effect on blood glucose and HDL however, it lowers cholesterol, triglycerides, LDL, and VLDL levels.

Parsaeimehr et al. (2014b) completed the base diet of Ross broiler chickens with 0, 150, 300, 450 and 600 mg/kg of L-carnitine and showed that use of L-carnitine in the diet reduced levels of triglycerides, cholesterol, LDL, VLDL, and elevated blood albumin and globulin. However, the effect of L-carnitine on the level of glucose, protein, and HDL was not significant. The use of L-carnitine on blood parameters other than the concentration of triglyceride was not significant in broiler chickens under thermal stress at 42 days of age (Shirali et al., 2015). Corduk et al. (2007) reported that the use of L-carnitine did not affect total serum cholesterol and triglyceride levels. In the study of Azadmanesh and Jahanian (2014), the use of carnitine increased triglyceride levels throughout the rearing period.

When gemfibrozil and L-carnitine were used in diets of broiler chickens, total cholesterol and serum triglyceride declined, although the differences were not statistically significant (Farrokhyan et al., 2014). Arsan and Tufan (2018) reported that the use of L-carnitine and chitosan oligo-saccharide had no significant effect on total cholesterol, triglyceride, HDL, LDL, VLDL, total protein and albumin concentration in serum of broiler chickens. The use of 300 mg/kg L-carnitine increased blood glucose levels in broiler chickens under thermal stress. However, L-carnitine supplementation at levels 0, 100, 200 and 300 mg/kg had no significant effect on cholesterol, albumin, protein and HDL in broiler chickens (Babazadeh Aghdam et al., 2015).

Research results of Taraz and Dastar (2008) showed that the use of L-carnitine supplementation in broiler diets had no significant effect on blood parameters such as cholesterol, total protein, albumin, triglyceride, glucose and blood uric acid. Usage of L-carnitine in herbal oil diet increased total protein, globulin, cholesterol, HDL, and LDL in blood serum of broiler chicken (Jalali et al., 2015). Fallah et al. (2016) revealed that broiler chickens Ross 308, fed with diet containing L-carnitine and terbutaline, had lower total cholesterol, HDL, and LDL than the control.

Corduk et al. (2007) reported that the use of complementary L-carnitine in broiler diets increased β -oxidation of fatty acids to produce adenosine triphosphate (ATP) energy and improved energy efficiency. Mehdizadeh Taklimi et al. (2015) showed that calcium and phosphorus levels of blood in broiler chickens were not affected by a diet containing L-carnitine.

The effect of a diet containing L-carnitine, ginger and vitamin E on serum paraoxonase activity and oxidative status indicated that all treatments increased serum paraoxonizations and decreased total oxidant status on 21, 28, 35 and 42 days of age, in comparison with the control group. Reducing glucose and increasing total protein was also reported (Rehman et al., 2017). Murali et al. (2013) fed chickens 900 mg/kg of L-carnitine and found that the treatment significantly reduced cholesterol and serum LDL-cholesterol levels compared to the control. The effect of L-carnitine on the levels of triglycerides, HDL, and VLDL was not significant.

Abd El-Wahab et al. (2015) showed that the lowest levels of cholesterol were obtained in chickens fed lysine (15.5 g/kg) and methionine (5.8 g/kg) plus 350 mg/kg L-carnitine. In the study of Parsaeimehr et al. (2014b), the L-carnitine diet had no significant effect on blood protein.

Hosseintabar et al. (2015) examined the effects of different levels of L-carnitine, lysine and methionine on blood parameters of broiler chickens Ross 308. In that 3×3 factorial design study, three levels of L-carnitine (0, 75 and 150 mg/kg) and 3 levels of

lysine and methionine (0, 15 and 30%) were used. The results showed that the diets supplemented with L-carnitine had a significant effect on uric acid, HDL, LDL, and total cholesterol. L-carnitine-, lysine- and methionine-fed chickens had the highest plasma uric acid and the lowest total cholesterol and LDL. Also, L-carnitine significantly reduced total cholesterol compared to control and lysine and methionine-fed chickens. Generally, the diet with 150 mg/L of carnitine and 15% of lysine and methionine was the best treatment to maintain the concentration of TC, LDL, and HDL. Jafari Golrokh et al. (2016) reported a decrease of cholesterol, triglycerides, LDL, alkaline phosphate (ALP) in chickens treated with L-carnitine.

From the above researches, it is concluded that positive and significant effects of L-carnitine on blood parameters of broiler chickens were evident. L-carnitine, as an edible anti-fat substance, reduced cholesterol, triglycerides, LDL, and VLDL, in most studies, and had a positive effect on blood parameters. In a few studies, the effect of L-carnitine on the improvement of blood parameters was not significantly different compared with the control. But in general, the effect of this supplement was positive in improving the blood parameters of broiler chickens.

Table 4. Effect of L-carnitine on blood parameters of broiler chickens

Reference	Applied treatment	Effects
Xu et al., 2003	25,50, 75, 100 mg/kg	Reduced serum triglyceride and increased free fatty acid levels
Rezaie et al., 2007	250 mg/kg	Reduced blood triglycerides, cholesterol, serum VLDL
Zhang et al., 2010	300, 600,900 mg/kg	Increased fatty acid catabolism and reduced serum triglyceride levels
Khajali and Khajali, 2014	200 mg/kg	Reduced malondialdehyde in plasma, reduced hematocrit and increased plasma nitric oxide
Tan et al., 2008	100 mg/kg	Reduced levels of plasma malondialdehyde
Yosefi et al., 2013	50, 150 mg/kg	Reduced levels of plasma malondialdehyde
Wang et al., 2013	100 mg/kg	Reduction of red blood cells, hemoglobin and hematocrit, malondialdehyde, serum triglyceride, glucose and uric acid, increase of activity of superoxide dismutase and GSH-PX and increased serum total protein
Zhang et al., 2010	300, 600, 900 mg/kg	Reduced triglycerides and cholesterol
Kheiri et al., 2011	60, 120 mg/kg	Reduced triglycerides and increased serum cholesterol levels
Parsaeimehr et al., 2013	150, 300, 450, 600 mg/kg	No significant effect on blood glucose, HDL, and a significant reduction in cholesterol, triglyceride, LDL and VLDL levels.
Parsaeimehr et al., 2014b	300 mg/kg	Reduced triglyceride, cholesterol, LDL and VLDL, increased albumin and globulin levels

Shirali et al., 2015	150, 300, 450, 600mg/kg	Significant and positive effects on blood triglyceride concentration
Corduk et al., 2007	100 mg/kg	No significant effect on total serum cholesterol and triglyceride levels
Azadmanesh and Jahanian, 2014	100 mg/kg	Increased triglyceride levels throughout the course
Farrokhyan et al., 2014	150, 300 mg/kg L- carnitine + 1, 2 mg/kg gemfibrozil	Reduced total serum cholesterol and triglyceride
Arslan and Tufan, 2018	100 mg/kg L- carnitine	No significant effect on total cholesterol, triglycerides, HDL, LDL, VLDL, total protein and albumin concentration in serum
BabazadehAghdam et al., 2015	100, 200, 300 mg/kg	Increased blood glucose but no significant effect on cholesterol, albumin, protein and HDL
Jalali et al., 2015	120 mg/kg	Increased total serum protein, globulin, cholesterol, HDL and LDL
Fallah et al., 2016	100 mg/kg L- carnitine plus 10 mg/kg terbutaline	Reduced total cholesterol, HDL, and LDL
Corduk et al., 2007	100 mg/kg	Increased oxidation of fatty acids and increased energy production
MehdizadehTaklimi et al., 2015	400, 600, 800 mg/kg	No significant effect on calcium and phosphorus levels
Rehman et al., 2017	500 mg/kg	Increased serum and total protein paroxonization activity, decreased total oxidant and glucose status
Murali et al., 2013	900 mg/kg	Decreased cholesterol, LDL levels and no significant effect on triglyceride, HDL and VLDL levels
Abd El Wahab et al., 2015	350 mg/kg	Reduce cholesterol levels
Parsaeimehr et al., 2014a	300 mg/kg	No significant effect on blood protein
Hosseintabar et al., 2015	75, 150 mg/kg	Positive effects on uric acid, HDL, LDL, and total cholesterol
JafariGolrokh et al., 2016	150, 300 mg/kg	Reduced cholesterol, triglycerides, LDL, and alkaline phosphate
Kheirkhah et al., 2009	100 , 200 mg/kg	No effect on the concentration of cholesterol or blood triglycerides
Taraz and Dastar, 2008	125, 250 mg/kg	No effect on blood parameters
Murali et al., 2015	900 mg/kg	Increased metabolism and facilitated the oxidation of fatty acids

Effect of L-carnitine on the microbial flora of broiler chickens

Hosseintabar et al. (2013) investigated the effect of L-carnitine, methionine-lysine on the microbial flora of broiler cecum. In that study, L-carnitine (0, 75 and 150 mg/kg), methionine-lysine (0, 15 and 30%)

were used at three levels. The results showed that there is a significant difference between the levels of L-carnitine and methionine-lysine in the total population of aerobic bacteria, producing lactic acid bacteria, *Escherichia coli* and lactobacilli at a probability level of 5%.

Table 5. Effect of L-carnitine on the microbial flora of broiler chickens

Reference	Applied treatment	Effects
Hosseintabar et al., 2013	75 , 150 mg/kg	Positive effect in reducing the total population of aerobic bacteria, producing lactic acid bacteria, <i>Escherichia coli</i> and lactobacillus

Effect of L-carnitine on the fatty acid profile and meat characteristics of broiler chickens

Abd El-Wahab et al. (2015) used two levels of L-carnitine (175 and 350 mg/kg) in the diet of broiler chickens containing methionine (6.5 and 8.5 g/kg) and lysine (13.5 and 15.5g/kg). The results of that study showed that L-carnitine significantly reduced lipid profiles in all 2 levels.

The effect of butyric acid (0 and 2 g) and L-carnitine (0, 125 and 250 mg) on broiler chicken meat color showed that statistically there was no significant difference between the treatments. However, L-carnitine at 125 milligrams level had the highest brightness and redness of breast meat among treatments. The effect of L-carnitine and butyric acid on the characteristics of thigh meat (yellowness, redness and brightness) was not significant. However, the chickens fed a diet containing 250 mg of L-carnitine had darker thigh meat compared to the other treatments. In that study, the chickens fed a diet containing 125 mg/kg

of L-carnitine had thigh meat with higher pH of. The maximum pH of the breast meat was 250 mg/kg of L-carnitine plus 2 g/kg of butyric acid. The researchers linked this study of the effect of L-carnitine on the brightness of meat color as a consequence of that material in preventing the oxidation of muscle myoglobin (Khatibjoo et al., 2016).

The results of Zhang et al. (2010) showed that the effect of L-carnitine (0, 300, 600 and 900 mg/kg) on pH of breast meat, colour brightness of breast and thigh meat, was not statistically significant. However, the effect of treatments on pH of thigh meat showed that using L-carnitine, increased pH of the thigh, redness of breast and thigh meat. The yellowness of thigh and breast meat decreased with L-carnitine usage compared to the control. Breast and thigh shear forces declined by using high levels of L-carnitine (600 and 900 milligrams). Corduk et al. (2007) showed that the use of L-carnitine (0 and 100 mg/kg) did not affect meat quality in broiler chickens.

Table 6. Effect of L-carnitine on the fatty acid profile of broiler chickens

Reference	Applied treatment	Effects
Abd El Wahab et al., 2015	175, 350 mg/kg	Reduced lipid profile

Table 7. Effect of L-carnitine on the characteristics of broiler chicken meat

Reference	Applied treatment	Effects
Khatibjoo et al., 2016	250 mg/kg	More darkness of thigh meat
Khatibjoo et al., 2016	125 mg/kg	Increased pH of thigh meat and brightness and redness of breast meat
Khatibjoo et al., 2016	250 mg/kg, 2 g/ kg butyric acid	Increased pH of breast meat
Zhang et al., 2010	300, 600, 900 mg/kg	Increased pH of the thigh, redness of breast and thigh meat
Corduk et al., 2007	100 mg/kg	No significant effect on meat quality

CONCLUSION

L-carnitine, as a nutritional substance was found effective in reducing fat content in the body of broiler chickens leading to resulting in the production of low-fat and healthier chickens without affecting the performance and qualitative characteristics of broiler chickens. Therefore, L-carnitine can be used at levels of 125-300 mg/L as an effective nutritional supplement to resolve the problem of fat accumulation as well as maintaining the health of chickens. Although higher levels of L-carnitine were also found effective, economic considerations, and cost relative to benefit

balance, the dose 300 mg/L is the one to be recommended.

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CONFLICT OF INTEREST

None declared by the authors.

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