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Dietary L-carnitine Influences Broiler Thigh Yield*

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ABSTRACT : L-carnitine promotes mitochondrial β-oxidation of long chain fatty acids and their subsequent transport across the inner mitochondrial membrane. Although the role of L-carnitine in fatty acid metabolism has been extensively studied, its role in live performance and carcass responses of commercial broilers is less understood. The objective of this research was to determine if L-carnitine fed at various levels in diets differing in CP and amino acids impacted on live performance and carcass characteristics of commercial broilers. Two floor pen experiments were conducted to assess the effect of dietary L-carnitine in grower diets. In Exp. 1, Ross×Hubbard Ultra Yield broilers were placed in 48 floor pens (12 birds/pen) and fed common diets to d 14. A two (0 or 50 ppm L-carnitine) by three (173, 187, and 202 g/kg CP) factorial arrangement of treatments was employed from 15 to 35 d of age (8 replications/treatment). An interaction ($p<0.05$) in carcass yield indicated that increasing CP (187 g/kg) resulted in improved yield in the presence of L-carnitine. Increasing CP from 173 to 202 g/kg increased ($p<0.05$) BW gain and decreased ($p<0.05$) feed conversion and percentage abdominal fat. Feeding dietary L-carnitine increased back-half carcass yield which was attributable to an increase ($p<0.05$) in thigh, but not drumstick, yield relative to carcass. In Exp. 2, Ross×Ross 708 broilers were fed common diets until 29 d. From 30 to 42 d of age, birds were fed one of seven diets: i) 200 g/kg CP, 0 ppm L-carnitine; ii) 200 g/kg CP, 40 ppm L-carnitine; iii) 180 g/kg CP, 0 ppm L-carnitine; iv) 180 g/kg CP, 10 ppm L-carnitine; v) 180 g/kg CP, 20 ppm L-carnitine; vi) 180 g/kg CP, 30 ppm L-carnitine; and vii) 180 g/kg CP, 40 ppm L-carnitine (6 replications of 12 birds each). BW gain, feed conversion, mortality (30 to 42 d), and carcass traits (42 d) were measured on all birds by pen. There were no treatment differences ($p<0.05$). However, the addition of 40 ppm L-carnitine in the 200 g CP/kg diet increased ($p = 0.06$) thigh yields relative to BW in comparison to birds fed diets without L-carnitine, which was further confirmed via a contrast analysis (0 vs. 40 ppm L-carnitine in the 200 and 180 g CP/kg diets; $p<0.05$). These results indicated that dietary L-carnitine may heighten metabolism in dark meat of commercial broilers resulting in increased relative thigh tissue accretion without compromising breast accretion. (**Key Words :** Broiler, L-carnitine, Carcass Yield, Amino Acid, Crude Protein)

INTRODUCTION

Broilers can synthesize L-carnitine de novo via lysine and methionine metabolism. In addition, dietary meals derived from animal origin are higher in L-carnitine than those of vegetable meals. L-carnitine is essential in broiler metabolism as long chain fatty acid transport across the mitochondrial membrane is dependent on L-carnitine. In addition, L-carnitine promotes β-oxidation of long chain fatty acids. Hence, broiler research concerned with L-carnitine typically assesses lipid metabolism and carcass composition.

Inconsistencies exist in results of broiler research with L-carnitine. Dietary addition of 25 (Xu et al., 2003) or 50 (Rabie et al., 1997 a,b; Rabie and Szilagyi, 1998) ppm L-carnitine have been shown to decrease abdominal fat pads in comparison to broilers receiving no supplemental dietary L-carnitine. However, Cartwright (1986), Baker and Sell (1994), Lien and Horng (2001), and Leibetseder (1995) demonstrated that the dietary addition of 50, 50 and 100, 160, and 200 ppm L-carnitine did not impact fat pad deposition in broilers, respectively. Moreover, broiler research studies with L-carnitine differ in terms of carcass composition as well. This study was conducted to determine the effect of dietary L-carnitine on live performance and carcass composition of two high-yield broiler strains. In addition, diets varying in CP were used in this study.

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MATERIALS AND METHODS

Broilers, housing, and management

Broilers were sourced from commercial broiler operations for two Exp. Exp. 1 and 2 were initiated when birds were 15 and 30 d of age, respectively. All broilers were vaccinated for Marek's disease at d 18 *in ovo*. Administration of Newcastle and infectious bronchitis vaccines were provided via coarse spray at hatch. Chicks were feather sexed and transported to the research facility which was identical for both Exp. The floor pens measured 0.92×1.22 m and were located on a concrete floor in a curtain-sided research facility. The pens contained one tube feeder (16 kg capacity), one drinker line containing 4 nipples, and shavings from soft-wood trees as bedding. The primary source of heat was two forced-air propane heaters. Cooling was accomplished with two cool cell pads. Four 60 cm and two 90 cm fans were used for minimum and transitional ventilation. Brooding temperature was set for 32, 30, and 27°C at wk 1, 2, and 3, respectively. House temperature was maintained between 19 and 22°C thereafter. Broilers were allowed 23 h light at 25 lx from placement (d 1) to termination of both Exp.

Experimental design and diets

A 2×3 factorial arrangement of treatments was used in Exp. 1. Ross×Hubbard Ultra Yield male broilers received common diets from 1 to 14 d of age that met or exceeded National Research Council (1994) recommendations. At d 15, dietary treatments (Table 1) were employed and were provided *ad libitum* to d 35. Treatments consisted of three CP levels (172.8, 187.2, and 201.6 g/kg of diet) and two L-

Table 1. Test diets and calculated composition

Ingredients	Experiment 1			Experiment 2	
	Control CP	-14.4 g/kg CP	-28.8 g/kg CP	Control CP	-17.26 g/kg CP
Corn	600.31	645.11	681.09	630.07	683.23
Soybean meal	309.55	268.34	228.52	287.68	243.17
Poultry fat	49.73	43.31	40.28	43.72	34.72
Dicalcium phosphate	17.51	17.80	18.12	15.48	15.78
Limestone	10.46	10.56	10.64	10.99	11.11
Sodium chloride	5.38	5.38	5.38	5.38	5.38
Premix[1]	2.50	2.50	2.50	2.50	2.50
Coban 60[2]	0.75	0.75	0.75	-	-
Sacox 60[3]	-	-	-	0.50	0.50
Choline chloride	0.28	0.41	0.55	0.35	0.49
Filler[4]	0.55	0.55	0.55	0.50	0.50
DL-methionine	2.29	2.66	3.05	2.05	1.69
L-lysine	0.64	1.97	3.28	0.79	0.95
L-threonine	0.05	0.64	1.23	-	-
Amino acid premix[5]	-	-	5.76	-	-
Calculated composition[6]					
CP (g/kg)	201.6	187.2	172.8	193.40	176.14
TSAA (g/kg)	8.10	8.10	8.10	7.68	6.94
Lys (g/kg)	10.3	10.3	10.3	9.87	8.88
Thr (g/kg)g	6.90	6.90	6.90	6.56	5.94
Ile (%)	7.70	7.00	7.00	7.34	6.60
ME (MJ/kg)	13.18	13.18	13.18	13.18	13.18
Ca (g/kg)	8.80	8.80	8.80	8.50	8.50
Available P (g/kg)	4.40	4.40	4.40	4.00	4.00
Na (g/kg)	2.30	2.30	2.30	2.30	2.30
Choline (mg/kg)	1,350	1,350	1,350	1,350	1,350
DEB (mEq/kg)	200	175	151	190	171

[1] Premix provided the following per kg of diet: vitamin A (vitamin A acetate) 7,718 IU; cholecalciferol 2,200 IU; vitamin E (source unspecified) 10 IU; menadione, 0.9 mg; B_{12}, 11 μg; choline, 379 mg; riboflavin, 5.0 mg; niacin, 33 mg; D-biotin, 0.06 mg; pyridoxine, 0.9 mg; ethoxyquin, 28 mg; manganese, 55 mg; zinc, 50 mg; iron, 28 mg; copper,7 mg; iodine, 1 mg; selenium, 0.2 mg.

[2] Provided 90 g of monensin sodium/907.2 kg of complete feed.

[3] Provided 60 g of salinomycin sodium/907.2 kg of complete feed.

[4] Filler represented inert ingredient (sand) to which L-carnitine was added.

[5] Amino acid premix represents 0.7 g/kg L-isoleucine, 0.84 g/kg L-valine, 0.17 g/kg L-tryptophan, 1.0 g/kg L-arginine, and 1.52 g/kg glycine to maintain minimums in formulation of 7.0, 7.9, 1.8, 11.0, and 1.65 (glycine+serine) g/kg, respectively. Analyzed values of amino acids are in agreement with calculated levels.

[6] Amino acids are presented as digestible levels. TSAA = total sulfur amino acids, Lys = lysine, Thr = threonine, Ile = isoleucine, Ca = calcium, P = phosphorus, Na = sodium, DEB = dietary electrolyte balance and is defined as: sodium+potassium-chloride.

carnitine levels (0 and 50 ppm). Each treatment diet was fed to eight replicate pens (12 birds/pen; 96 birds/treatment). L-carnitine was added to test diets in place of the inert filler (sand). All diets had equal dietary ME, calcium, available phosphorus, sodium, choline, digestible lysine, digestible sulfur amino acids, and digestible threonine. Test diets were ground, digested and diluted with 1 N hydrochloric acid, and analyzed for amino acids by HPLC. Test diets were also digested, neutralized and diluted in perchloric acid, and analyzed for L-carnitine by an enzymatic assay using a radioisotope (Parvin and Pande, 1977).

Seven dietary treatments were used in Exp. 2 (Table 1). Each dietary treatment was fed to six pens (12 birds/pen) of Ross×Ross 708 male broilers from 30 to 42 d of age. From 1 to 29 d of age broilers received two common diets meeting or exceeding known nutrient needs (National Research Council, 1994). Dietary treatments consisted of: i) 193.4 g/kg CP with no L-carnitine; ii) 193.4 g/kg CP plus 40 ppm L-carnitine; iii) 176.1 g/kg CP with no L-carnitine; iv) 176.1 g/kg CP plus 10 ppm L-carnitine; v) 176.1 g/kg CP plus 20 ppm L-carnitine; vi) 176.1 g/kg CP plus 30 ppm L-carnitine; and vii) 176.1 g/kg CP plus 40 ppm L-carnitine. Dietary analyses of amino acids and L-carnitine followed the procedure of Exp. 1. Dietary additions of L-carnitine were added at the expense of the filler. Although ME, calcium, available phosphorus, sodium, and choline were equal, amino acid minimums were lower in the 176.1 vs. the 193.4 g/kg CP diet. However, diets were formulated to minimum digestible ratios to lysine of: sulfur amino acids (78); threonine (66), and isoleucine (74).

Measurements

Body weight and feed intake by pen were measured at the onset and ending of each experiment. Feed conversion was calculated by dividing total pen feed consumption by total BW gain. Mortality were collected and weighed daily. In Exp. 1, feed was removed from birds at d 35 after BW was obtained. Twelve h later, all broilers were processed and carcass fat and weight were obtained. After carcasses were allowed to chill in ice for 20 h, half of the carcasses from each pen were randomly selected to be further processed to obtain: deboned-skinless breast meat, wings, thighs, and drumsticks. Identical processing measurements were obtained in Exp. 2. However, at d 42 in Exp. 2, all birds were processed and all carcasses were de-boned. Care was taken so that drumsticks, thighs, wings, pectoralis major and pectoralis minor were removed by five stationary cutters on a moving debone line. Hence, each cutter made the same cut on every carcass.

Statistical analysis

Randomized complete blocks were used in both experiments of which data were analyzed using the GLM procedure of SAS (1996). Each pen of broilers represented an experimental unit for analyses. Means were compared for significant ($p \leq 0.05$) differences using the repeated *t* test of the LSMEANS option of SAS (1996). Statements of significance are $p \leq 0.05$ unless otherwise noted. In Exp. 2, further analyses by a set of prespecified contrasts were conducted.

RESULTS AND DISCUSSION

There is an increasing trend to feed broilers diets composed solely of protein contributing ingredients from vegetable sources. Meat and fish meals are rich sources of L-carnitine. For example, the highest concentration of L-carnitine in animals is in skeletal muscle and the heart (Bremer, 1983). Although poultry can synthesize L-carnitine from the breakdown of lysine and methionine, the primary source of L-carnitine for poultry, as in most animals, is the diet. Hence, L-carnitine was evaluated in test diets in Exp. 1 and Exp. 2 devoid of animal and fish meal sources.

L-carnitine was added to the diet in place of a filler so that dietary nutrient composition would not change. Because ingredients composed of animal protein meals are rich in L-carnitine, test diets contained corn and soybean meal as intact protein contributing ingredients (Table 1). Test diets, devoid of L-carnitine, were analyzed to contain 2 ppm in Exp. 1 and 2 (Tables 2 and 3). Test diets containing L-carnitine in Exp. 1 were analyzed to contain 55.2 ppm L-carnitine. In Exp. 2, test diets containing L-carnitine, treatments 2, 4, 5, 6, and 7, were analyzed to contain 39, 17, 18, 37, and 54 ppm L-carnitine, respectively. Mixing uniformity and diet sample collection may have contributed to the lack of spread between treatments 4 (10 ppm calculated L-carnitine) and 5 (20 ppm calculated L-carnitine). However, diet analyses indicate that test diet additions and control diet levels of L-carnitine were achieved.

Amino acid analysis indicated that variations in amino acid density were achieved. Rabie et al. (1997a) fed various levels of CP (180, 200, and 220 g/kg of diet) in the absence or presence (50 ppm) of supplemental L-carnitine. Interactions occurred in 18 to 25 and 25 to 32 d BW gain and feed conversion indicating that the lowest level of CP provided good growth and conversion only if dietary L-carnitine was supplemented (Rabie et al., 1997a). Therefore, Exp. 1 was conducted with varying dietary CP, but equal levels of sulfur amino acids, lysine, and threonine. Also, isoleucine was formulated to a minimum ratio to lysine of 70. Rodehutscord et al. (2002) varied dietary L-carnitine in balance trials for broilers and found that L-carnitine did not impact N balance or protein utilization. As such, Exp. 2 was conducted to assess differences in dietary CP and amino

Table 2. Impact of diets differing in dietary L-carnitine and CP levels from 15 to 35 d on growth and carcass responses of Ross× Hubbard Ultra Yield male broilers, Exp. 1

CP (g/kg)	L-carnitine (mg/kg)	BW gain (kg/bird)	Feed/gain (kg/kg)	Whole carcase	Breast meat	Thighs	Drumsticks	Wings	Abdominal fat
				---------- (% of BW) ----------					
172.8		1.098[b]	1.94[a]	65.37	19.08	12.58	9.62	8.00	1.26[a]
187.2		1.111[b]	1.92[a]	65.84	18.79	12.54	9.90	7.97	1.15[ab]
201.6		1.206[a]	1.82[b]	65.13	18.59	12.32	9.70	7.80	1.09[b]
	0	1.140	1.89	65.57	19.00	12.40	9.72	7.87	1.15
	50	1.137	1.90	65.33	18.64	12.55	9.76	7.97	1.18
172.8	0	1.109	1.92	66.19[ab]	19.50	12.56	9.62	7.91	1.19
187.2	0	1.102	1.92	65.20[abc]	18.61	12.39	9.89	7.87	1.15
201.6	0	1.209	1.82	65.32[abc]	18.90	12.26	9.65	7.83	1.11
172.8	50	1.086	1.96	64.55[c]	18.66	12.60	9.62	8.08	1.33
187.2	50	1.120	1.91	66.48[a]	18.97	12.68	9.92	8.06	1.15
201.6	50	1.204	1.82	64.94[bc]	18.29	12.38	9.75	7.76	1.07
SEM		0.028	0.02	0.47	0.27	0.14	0.12	0.10	0.05
CP		0.001	0.001	0.315	0.212	0.137	0.059	0.088	0.014
L-carnitine		0.898	0.514	0.528	0.111	0.201	0.651	0.246	0.538
CP×L-carnitine		0.756	0.436	0.014	0.079	0.647	0.927	0.332	0.231

[a-c] Means within a column not sharing a common superscript differ.

acid balance, in the presence or absence of dietary L-carnitine. It was hypothesized that beneficial L-carnitine effects would be observed in vegetable based diets marginal in supply of dietary CP, methionine, and lysine.

L-carnitine treatment differences did not occur in Exp. 1 (Table 2). Birds fed 201.6 g/kg CP in comparison to birds fed 187.2 or 172.8 g/kg CP had improved p≤0.05) BW gain and feed:gain. The former trend (p≤0.05) occurred in abdominal fat except birds fed the diet containing 187.2 g/kg CP had intermediate relative abdominal fat. Drumstick yield was higher (p = 0.06) in birds fed 187.2 vs. 172.8 g/kg CP. Although amino acid density differences were not the main objective of this research, it must be pointed out the breast meat yield differences did not occur.

The inability of dietary L-carnitine to decrease abdominal fat in Exp. 1 is in disagreement (Rabie et al., 1997a, b; Rebie and Szilagyi, 1998; Xu et al., 2003) and in agreement (Cartwright, 1986; Baker and Sell, 1994; Leibetseder, 1995; Lien and Horng, 2001) with past research. Further statistical analysis of Exp. 1 was conducted to further assess carcass characteristics. Expressing abdominal fat relative to carcass as affected by L-carnitine had a probability of 0.487. However, thighs and thighs plus drumsticks relative to carcass were higher (p = 0.003 and p = 0.048, respectively) in birds fed L-carnitine (data not presented). Therefore, Exp. 2 was conducted with the hypotheses to further measure potential L-carnitine effects on thigh and drumstick yield while utilizing varying L-carnitine levels and further processing all broilers.

In Exp. 2, only thigh yield (p = 0.060) and abdominal fat (p = 0.081) were affected by dietary treatments (Table 3). Contrast analyses for abdominal fat revealed (p = 0.004) high dietary CP, but not L-carnitine, reduced abdominal fat. However, contrast analyses for thigh yields indicated that the dietary addition of 40 ppm L-carnitine increased thigh yield in the high (p = 0.023) and low (p = 0.022) CP diets. Dietary supply of lysine and methionine did not affect L-carnitine's impact on thigh yield. Dietary lysine and methionine in the 176 g/kg CP diet may have been adequate for *de novo* synthesis of L-carnitine, as noted by the absence of an abdominal fat response. L-carnitine's impact on thigh yield (skin on and bone in) may be attributable to the type of muscles located in the thigh. Hence, thigh muscle represents red muscle fibers that are rich in myoglobin and have high mitochondrial oxidative metabolism (Ueda et al., 2005). L-carnitine and myoglobin concentration are positively correlated (Shimada et al., 2004). White leghorns have almost twice the L-carnitine in their muscles as broilers (Shimada et al., 2004). Indeed, much of this difference is attributable to more relative red muscle types in layers than broilers. Indeed, the effect of L-carnitine on thigh yield may be attributable to its role in long-chain fatty acid transport across the inner mitochondrial membrane. The proportion of skeletal muscle vs adipose tissue was not assessed in Exp. 1 or 2. It may be hypothesized that the muscle to fat ratio was increased as an L-carnitine deficiency has been shown to impair fatty acid oxidation (Treem et al., 1988).

IMPLICATIONS

Dietary L-carnitine had no impact on broiler live performance and abdominal fat deposition. Thigh yields relative to BW were increased in birds fed 40 ppm L-

Table 3. Impact of diets differing in dietary L-carnitine and CP levels from 30 to 42 d on growth and carcass responses of Ross×708 male broilers, Exp. 2

Treatment[1]	BW gain (kg/bird)	Feed/gain (kg/kg)	Whole carcase	Breast meat	Thighs	Drumsticks	Wings	Abdominal fat
			---------- % of BW ----------					
1. 193 CP+0 L-carnitine	0.855	2.40	69.60	21.11	13.35	9.98	8.31	1.35
2. 193 CP+40 L-carnitine	0.842	2.28	69.93	21.09	13.70	9.93	8.02	1.33
3. 176 CP+0 L-carnitine	0.796	2.49	69.55	21.12	13.42	9.79	8.12	1.46
4. 176 CP+10 L-carnitine	0.829	2.40	69.87	21.27	13.71	9.82	8.13	1.49
5. 176 CP+20 L-carnitine	0.813	2.43	69.50	20.96	13.41	9.80	8.09	1.43
6. 176 CP+30 L-carnitine	0.831	2.51	68.42	21.05	13.64	9.91	8.23	1.53
7. 176 CP+40 L-carnitine	0.800	2.49	70.08	21.03	13.63	9.87	8.20	1.44
SEM	0.022	0.08	0.46	0.22	0.10	0.06	0.11	0.05
Probability								
t test	0.450	0.421	0.238	0.976	0.060	0.200	0.585	0.081
1 vs. 2					0.023			0.800
3 vs. 7					0.022			0.779
3 vs. 4 through 7					0.083			0.179
1 and 2 vs. 3 through 7								0.004

[1] CP and L-carnitine are expressed as g/kg and mg/kg, respectively.

carnitine independent of CP, methionine, and lysine level.

REFERENCES

Baker, D. L. and J. L. Sell. 1994. Dietary L-carnitine did not influence performance and carcass composition of broiler chickens and young turkeys fed low-or high-fat diets. Poult. Sci. 73:281-287.

Bremer, J. 1983. Carnitine-metabolism and functions. Physiol. Rev. 63:1420-1480.

Cartwright, A. L. 1986. Effect of L-carnitine and dietary energy concentration on body weight and body lipid of growing broilers. Poult. Sci. 65 (Suppl.1):21 (Abstr.).

Leibetseder, J. 1995. Untersuchungen über die wirkungen von L-Carnitin beim huhn. Arch. Anim. Nutr. 48:97-108.

Lien, T. F. and Y. M. Horng. 2001. The effect of supplementary dietary L-carnitine on the growth performance, serum components, carcase traits and enzyme activities in relation to fatty acid β-oxidation of broiler chickens. Br. Poult. Sci. 42:92-95.

National Research Council 1994. Nutrient requirement of poultry. 9th revision edition. National Academy Press, Washington, DC.

Parvin, R. and S. V. Pande. 1977. Microdetermination of (-) L-carnitine and L-carnitine acetyl transferase. Analyt. Biochem. 79:190-201.

Rabie, M. H., M. SzilÁgyi and T. Gippert. 1997a. Effects of dietary L-carnitine supplementation and protein level on performance and degree of meatness and fatness of broilers. Acta Biologica Hung. 48:221-239.

Rabie, M. H., M. SzilÁgyi, T. Gippert, E. Votisky and D. Gerendai. 1997b. Influence of dietary L-carnitine on performance and carcass quality of broiler chickens. Acta Biologica Hung. 48:241-252.

Rabie, M. H. and M. Szilágyi. 1998. Effects of L-carnitine supplementation of diets differing in energy levels on performance, abdominal fat content, and yield and composition of edible meat of broilers. Br. J. Nutr. 80:391-400.

Rodehutscord, M., R. Timmler and A. Dieckmann. 2002. Effect of L-carnitine supplementation on utilization of energy and protein in broiler chicken fed different dietary fat levels. Arch. Tierernahr. 56:431-441.

SAS Institute. 1996. SAS User's Guide: Statistics, Version 7.0. Cary, NC, Statistical Analysis Institute, Inc.

Shimada, K., Y. Sakuma, J. Wakamatsu, M. Fukushima, M. Sekikawa, K. Kuchida and M. Mikami. 2004. Species and muscle differences in L-carnitine levels in skeletal muscles based on a new simple assay. Meat Sci. 68:357-362.

Treem, W. R., C. A. Stanley, D. N. Finegold, D. E. Hale and P. M. Coats. 1988. Primary carnitine deficiency due to a failure of carnitine transport in kidney, muscle and fibroblasts. New England J. Med. 319:1331-1336.

Ueda, M., K. Watanabe, K. Sato, Y. Akiba and M. Toyomizu. 2005. Possible role for avPGC-1α in the control of expression of fiber type, along with avUCP and avANT mRNAs in the skeletal muscles of cold-exposed chickens. FEBS let. 579:11-17.

Xu, Z. R., M. Q. Wang, H. X. Mao, X. A. Zhan and C. H. Hu. 2003. Effects of L-carnitine on growth performance, carcass composition, and metabolism of lipids in male broilers. Poult. Sci. 82:408-413.