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Influence of Coenzyme Q10 Supplementation in High Energy Broiler Diets on Production Performance, Hematological and Slaughter Parameters under Higher Environmental Temperature

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ABSTRACT

An experiment was carried out to study the effect of CoQ10 supplementation at 20 and 40 mg kg^{-1} in high energy diets under higher environmental temperature. The trial was carried out with 216 days old Cobb 400 broiler chicks divided into four treatments with nine replicates containing six birds in each. The treatments include normal energy diet (NE) (G1) (as per breeder's specifications) and high energy (HE, Normal energy plus 100 kcal) diet without (G2) and with CoQ10 supplementation at 20 (G3) and 40 (G4) mg kg^{-1}. The Temperature Humidity Index (THI) during the study ranged from 24.46-33.05°C. The bird's growth performance, feed intake, feed efficiency, its serum lipid, mineral profile, serum antioxidant activity, muscle lipid and CoQ10 content, slaughter parameters cost of live weight gain were studied. There was no significant difference in the body weight gain, feed intake, feed efficiency in the growth periods and slaughter parameters among the treatment groups, whereas the production score, higher intestinal length and better feed cost per kg of live weight gain was observed in NE fed groups than the other three groups. The serum and muscle lipid content was reduced and serum antioxidant activity was increased with on CoQ10 supplementation at 20 and 40 mg kg^{-1} in the diet.

Key words: Coenzyme Q10 (CoQ10), body weight gain, serum antioxidant activity, lipid profile, temperature

INTRODUCTION

Global warming is one of the major concerns in poultry production. Intensive genetic selection for faster growth rate means that modern broiler chickens were susceptible to lots of stresses like heat stress, metabolic stress (Deeb and Cahaner, 2002). The broilers exposed to an environmental temperature of 32°C were subjected to heat stress, which resulted in decreased feed intake by 14%, as compared to those kept at thermo neutral zone temperature; this reduction in feed intake is to reduce metabolic heat production (Sahin *et al*., 2009). Hai *et al.* (2000) reported that the activities of digestive enzymes trypsin, chymotrypsin and amylase were significantly reduced when animals were kept at high temperature (32°C) conditions. Heat stress also decreases the serum and liver concentrations of vitamins (C, E and A) and minerals (Fe, Zn, Se and Cr) and also influence the immune response of poultry (Donker *et al*., 1990). There will be an increased rate of free radical production in the body due to an increase in body temperature (Altan *et al*., 2000, 2003) and also by increase in whole body oxygen consumption (Sen, 1995). This increased oxygen consumption increased Reactive Oxygen Species (ROS) production (Clanton, 2007). Heat stress

increases the oxidative stress in broilers by increasing the level of Reactive Oxygen Species (ROS) in the body (Mujahid *et al*., 2007). The sources of ROS production include the mitochondria, peroxisomes, cytochrome P450 metabolism and inflammatory cell activation (Inoue *et al*., 2003). Mitochondrion is one of the predominant sources of ROS production in the system (Koren *et al*., 1983). Urso and Clarkson (2003) reported that 2-5% of the total oxygen consumed by mitochondria undergo one-electron reduction with the generation of superoxide. In addition, high environmental temperature affected the broiler performance (Al-Homidan, 2004) by changes in the energy, protein, lipid and mineral metabolisms, blood gases, acid-base and electrolyte balances, as well as hemoglobin concentration (Siegel, 1980).

In the biological systems, some of the biological antioxidant such as coenzyme Q10, superoxide dismutase, glutathione peroxidase, etc., counteract these stressors (Mates *et al.,* 1999; Kapoor and Kapoor, 2013; Fathi, 2015). Antioxidant nutrient supplementation, especially vitamin C, E, A, zinc and chromium, can be used to attenuate the negative effects of environmental stress (Kafri and Cherry, 1984; Mowat, 1994). In heat stress conditions, the naturally occurring biological compounds are insufficient to ameliorate the effects of free radicals (Harmon *et al*., 1997). Under field conditions, dietary supplementation of anti-stress-vitamins, minerals, antioxidants like lycopene, lutein, herbals like *Withania somnifera*, *Ocimum sanctum*, etc. have been tried with varying degrees of success to reduce the effects of heat stress. In the tropical countries, the limitation of providing an ideal environmental condition for poultry rearing is the high environmental temperature which is above the thermal neutral zone for most part the year. Hence, the broilers reared in these geographical regions are exposed to heat stress.

To achieve higher growth performance, nutritionist attempt to increase the density of the nutrients in the diet. Since, dietary energy constitutes the major cost of broiler diet, attempts to improve the efficiency of energy utilization and minimize the energy wastage will help in improving the profitability of broiler farming. One such compound is coenzyme Q10, which is essential for ATP production and also acts, as an antioxidant which might be helpful in the reducing the effects of heat stress.

Coenzyme Q10 (CoQ10), an obligatory component of the mitochondrial electron transport chain, which is essential for ATP generation (Demirci, 2014). The CoQ10 acts as a redox electron carrier in the mitochondria (Zhou *et al*., 2005). This mitochondrial component has been used for many years as a dietary supplement intended to promote good health by trapping free radicals and the interest for this molecule comes from the fact of this role as a redox link in the mitochondrial electron transport chain and are important lipophilic antioxidant (Ochoa *et al*., 2005). Geng *et al.* (2004a, 2007) and Fathi *et al.* (2011) reported that this lipid-soluble compound involved in the mitochondrial adenosine triphosphate (ATP) synthesis and reduces the mortality due to ascites in broilers. Under prevailing tropical conditions, where the birds are subjected to heat stress, supplementation of coenzyme Q10 is expected to act as an antioxidant and improve the energy utilization at cellular level and thereby expected to improve the performance of broilers. Hence, this study was carried out whether the supplementation of CoQ10 at two energy levels will able to provide any beneficial effect on heat stressed birds.

MATERIALS AND METHODS

Birds and dietary treatments: Coenzyme Q10 (Qzyme®, manufactured by Agranco, USA Code No. DV100-12) was obtained and its activity was estimated, based on the method described by Ioana *et al.* (2009). Based on the maximum absorbance of the reduced form of Coenzyme Q10

at 300 nm solubilized in n-propanol against standard CoQ10 obtained from Sigma. The content of CoQ10 was found to be 20%. The biological experiment was conducted with 216 days old Cobb 400 broiler chicks. The chicks were wing banded on day one and weighed individually, then assigned randomly into four experimental groups with nine replicates with six chicks in each. Each replicate had even number of male and female chicks. Completely randomized design was followed. The treatments were normal energy diet (NE) (as per breeder's specifications) (G1), high energy (HE, Normal energy plus100 kcal) diet without CoQ10 supplementation (G2), high energy diet supplemented with CoQ10 at 20 mg kg^{-1} (G3) and 40 mg kg^{-1} (G4). All the diets are formulated to have isocalorific, isonitrogenous, isolysine and isomethionine levels were maintained within each energy groups. The chemical composition of the experimental diet used in this experiment are shown in Table 1.

Management and sampling: All the birds were reared under common managemental practices and observations of live weight, feed intake were taken at biweekly interval and feed efficiency was calculated. Twelve birds per treatment (six males and six females) were sacrificed and samples were collected. Production score was used as an index in the production of broiler chickens (Suzuki and Shibata, 1989). It was calculated as follows:

$$\text{Production score} = \frac{\text{Average body weight in kg} \times \text{Survival rate in percent}}{\text{Average market age in day} \times \text{Feed conversion}} \times 100$$

The daily maximum and minimum temperature and relative humidity inside the shed were recorded and temperature humidity index was calculated as per, Tao and Xin (2003):

$$THI_{broilers} = 0.85 \times T_{db} + 0.15 \times T_{wb}$$

Where:
THI = Temperature humidity index (°C)
T_{db} = Dry-bulb temperature (°C)
T_{wb} = Wet-bulb temperature (°C)

Laboratory analysis: The biological samples-blood, serum and muscle were collected. The serum were analyzed for antioxidant activity, lipid and minerals (calcium, phosphorus, sodium, potassium). The breast muscle samples were analyzed for its cholesterol and CoQ10 content. The collected blood was allowed to clot and centrifuged for 10 min at 2000 rpm to separate the serum. Serum samples were analyzed for total cholesterol, triglycerides, HDL cholesterol, total

Table 1: Nutrients composition (% DM) of broiler pre starter, starter and finisher diets

	Pre-starter		Starter		Finisher	
Nutrients (%)	Normal energy	High energy	Normal energy	High energy	Normal energy	High energy
Crude protein	22.65	23.30	21.65	21.75	19.70	20.21
Metabolizable energy (kcal kg^{-1})	3000	3100	3125	3225	3250	3350
Calcium	0.96	0.96	0.95	0.95	0.90	0.90
Available phosphorus	0.45	0.45	0.47	0.47	0.46	0.46
Lysine	1.42	1.47	1.25	1.29	1.14	1.18
Methionine	0.62	0.64	0.59	0.61	0.55	0.57

DM: Dry matter

protein, albumin and globulin. The total cholesterol content was estimated by one-step method of Wybenga *et al.* (1970), triglyceride was estimated as per Bucolo and David (1973) and HDL cholesterol was estimated as per Seigler and Wu (1981). The LDL cholesterol was calculated by Friedewald equation Friedewald *et al.* (1972). The biochemical kits used for these assays were purchased from M/s. Span® Diagnostics Ltd., Sachin, India.

The breast muscle samples were chopped and minced with mortar and pestle. The total lipid was extracted from muscle tissue samples as per the method suggested by Folch *et al.* (1957). The extracted muscle cholesterol was estimated by one-step method of Wybenga *et al.* (1970). The muscle CoQ10 was extracted using chloroform by Krizman *et al.* (2012) and quantified using the Ioana *et al.* (2009) method against standard CoQ10 (Sigma®). The muscle QCI a measure of oxidative stress was calculated as follows:

$$\text{CoQ10} - \text{cholesterol index} = \frac{\text{Coenzyme Q10 mg kg}^{-1}\text{ muscle tissue}}{\text{Cholestrol mg kg}^{-1}\text{ of muscle tissue}} \times 100$$

The serum calcium, sodium and potassium levels were determined using flame photometer as per, AOAC (1995). Serum phosphorus was quantified as inorganic phosphorus (in acidic medium) by reacting with ammonium molybdate to form phosphomolybdate complex, which was quantified at 340 nm (Miller *et al*., 1994).

Serum activity of superoxide dismutase was measured by the method of Marklund and Marklund (1974), glutathione peroxidase activity was measured according to Rotruck *et al.* (1973) method, reduced glutathione was measured according to the method of Ellman (1959), as described by Bulaj *et al.* (1998), serum malonaldehyde (MDA) was measured according to Salih *et al.* (1987) and Vitamin E level was estimated in the serum sample as per the method of Fabianek *et al.* (1968). The economics of raising broilers up to six weeks with different levels of CoQ10 supplementation and nutrient density was calculated based on the actual cost of feed per kg weight gain.

Statistical analyses: The data collected on various parameters were subjected to statistical analyses as per of Snedecor and Cochran (1989) and the means of different experimental groups were tested for statistical significance by Duncan's multiple range test (Duncan, 1955).

RESULTS

The mean maximum and minimum temperatures, relative humidity and Temperature Humidity Index (THI) are presented in Table 2. The trial was carried when the maximum temperature ranged from 21.18-34.26°C with relative humidity 37.35-68.40% and THI 25.35-32.47°C. The observation suggested that the environmental condition was above than the ideal recommended THI 20.8°C for broilers (Purswell *et al*., 2012) and the birds were maintained under higher environmental temperature during the experimental period.

Table 2: Temperature, relative humidity and temperature humidity index inside the experimental house

	Temperature (°C)		Relative humidity (%)		Morning (°C)		Evening (°C)		THI (°C)	
Periods	Max	Min	Max	Min	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Morning	Evening
Pre-starter	33.33	21.00	71.27	41.47	25.67	22.00	33.33	23.53	25.12	31.86
Starter	34.67	19.67	63.87	31.73	25.13	20.64	34.29	22.36	24.46	32.50
Finisher	34.80	22.87	70.07	38.85	27.07	23.07	34.67	23.87	26.47	33.05

Max: Maximum, Min: Minimum, THI: Temperature humidity index

The results of body weight gain, feed intake, feed efficiency and production score at biweekly intervals and overall (0-6 weeks) growth period and production score are presented in Table 3. During the 0-2 weeks, growth period similar body weight gain was observed between the normal energy and high energy with CoQ10 at 20 mg kg^{-1} diet groups, which is significantly, higher than the other two groups. The feed intake in the normal energy group, was higher ($p<0.05$), than the other three groups. The feed efficiency was better ($p<0.05$) in high energy group supplemented with CoQ10 at 20 mg kg^{-1} diet than the other two high energy groups. In the starter, finisher phases and overall growth period the production performances were comparable in all the four treatments. The production score was less in high energy unsupplemented and 40 mg kg^{-1} CoQ10 supplemented group, when compared to normal energy.

Table 3: Influence of coenzyme Q10 at two levels on the body weight gain (g), feed intake (g) feed efficiency of broilers at different growth phases and production score

Ages (weeks)	G1	G2	G3	G4	p-value
Body weight gain (g)					
0-2	352±05^{a}	303±06^{b}	347±06^{a}	294±05^{b}	0.001
3-4	752±18	691±23	716±26	726±22	0.29
5-6	932±25	982±31	960±50	987±48	0.65
0-6	2033±41	1977±51	2023±58	1996±49	0.86
Feed intake (g)					
0-2	422±05^{a}	374±10^{b}	396±10^{b}	384±11^{b}	0.006
3-4	1035±30	956±32	963±20	994±26	0.23
5-6	1844±24	1978±58	1849±79	1948±43	0.22
0-6	3301±44	3307±71	3208±91	3325±57	0.63
Feed efficiency					
0-2	1.20±0.02^{bc}	1.23±0.03^{b}	1.14±0.03^{c}	1.30±0.03^{a}	0.01
3-4	1.38±0.05	1.38±0.03	1.34±0.04	1.37±0.02	0.92
5-6	1.98±0.04	2.01±0.17	1.93±0.11	1.98±0.07	0.28
0-6	1.62±0.02	1.67±0.06	1.59±0.05	1.67±0.02	0.50
Production score	323.8±9.4^{a}	252.6±20.6^{b}	293.1±1.8^{ab}	272.0±16.6^{b}	0.05
Mortality % (0-6)	0	16.67	9.26	12.96	-

^{a,b,c}Means with at least one common superscript in a row do not differ significantly ($p>0.05$), G1: Normal energy diet, G2: High energy diet without C_0Q10 supplementation at 20 mg kg^{-1}, G3: High energy diet with C_0Q10 supplementation at 20 mg kg^{-1}, G4: High energy diet with C_0Q10 supplementation at 40 mg kg^{-1}, Normal energy diet: As per breeder's specification, High energy dirt: Normal energy plus 100 kcal

Table 4: Influence of coenzyme Q10 at two levels on the serum lipid, mineral profile, antioxidant activity and muscle parameters

Parameters	G1	G2	G3	G4	p-value
Serum lipid profile (mg dL^{-1})					
Triglycerides	18.29±1.60^{b}	28.72±1.63^{a}	19.81±1.04^{b}	21.63±0.84^{b}	0.002
Total cholesterol	127.07±3.98^{c}	173.92±1.98^{a}	146.96±1.70^{b}	152.15±2.61^{b}	0.001
HDL-Cholesterol	19.58±3.46	15.45±3.21	17.18±1.05	18.87±0.91	0.647
LDL-Cholesterol	103.84±4.90^{c}	152.73±0.79^{a}	125.82±1.19^{bc}	139.47±1.84^{ab}	0.002
Serum mineral profile (mg dL^{-1})					
Calcium	9.07±0.22^{a}	8.48±0.10^{b}	8.30±0.10^{b}	8.32±0.12^{b}	0.001
Phosphorus	4.90±0.20^{a}	4.06±0.32^{b}	3.96±0.17^{b}	4.02±0.24^{b}	0.025
Sodium	157.0±5.4	160.7±1.2	161.1±2.2	159.40±3.10	0.62
Potassium	10.5±1.6	11.1±1.3	9.8±0.6	12.09±2.40	0.82
Serum antioxidant activity					
Superoxide dismutase (U mL^{-1})	4.58±0.16^{a}	3.91±0.15^{b}	4.67±0.11^{a}	4.43±0.13^{a}	0.002
Reduced glutathione	14.77±0.35^{b}	14.32±0.42^{b}	16.94±0.40^{a}	16.61±0.39^{a}	0.001
Glutathione peroxidase	7.93±0.28^{ab}	6.98±0.42^{b}	8.91±0.24^{a}	8.06±0.47^{ab}	0.04
Malonaldehyde (nmol mL^{-1})	7.94±0.15^{ab}	8.57±0.46^{a}	7.08±0.26^{b}	7.47±0.34^{b}	0.02
Vitamin E (mg mL^{-1})	0.43±0.10^{c}	0.60±0.05^{bc}	0.82±0.03^{a}	0.73±0.07^{ab}	0.003
Muscle cholesterol (mg dL^{-1})	98.96±8.32^{a}	103.78±12.07^{a}	65.56±6.39^{b}	84.30±9.53^{ab}	0.025
Muscle CoQ10 content (mg kg^{-1})	8.93±0.44^{b}	9.20±0.27^{b}	10.50±0.33^{a}	9.64±0.39^{ab}	0.021
QCI	9.82±0.99^{b}	11.22±2.28^{b}	17.66±1.69^{a}	13.05±1.57^{ab}	0.012

^{a,b,c}Means with at least one common superscript in a row do not differ significantly ($p>0.05$), G1: Normal energy diet, G2: High energy diet without C_0Q10 supplementation at 20 mg kg^{-1}, G3: High energy diet with C_0Q10 supplementation at 20 mg kg^{-1}, G4: High energy diet with C_0Q10 supplementation at 40 mg kg^{-1}, Normal energy diet: As per breeder's specification, High energy dirt: Normal energy plus 100 kcal

Table 5: Influence of coenzyme Q10 at two levels on the slaughter parameters

Parameters	G1	G2	G3	G4	p-value
Dressing(%)	68.22±0.64	71.44±0.64	70.78±0.85	70.69±1.45	0.10
Giblet weight (g kg^{-1} b.wt.)	42.73±1.01	42.89±1.05	41.16±0.77	41.51±1.93	0.71
Gizzard weight (g kg^{-1} b.wt.)	18.34±0.71	19.91±0.76	18.06±0.56	18.04±0.77	0.21
Liver weight (g kg^{-1} b.wt.)	19.72±0.80	18.62±0.45	18.56±0.71	18.94±1.09	0.72
Heart weight (g kg^{-1} b.wt.)	4.67±0.30	4.36±0.18	4.53±0.33	4.53 ±0.29	0.89
Abdominal fat (g kg^{-1} b.wt.)	8.95±0.73	8.80±0.91	8.06±0.84	11.35±1.21	0.09
Spleen weight (g)	2.17 ±0.21	2.17 ±0.21	2.50 ±0.23	2.33 ±0.19	0.63
Intestinal length (cm)	189.17±4.76^{b}	198.50±3.23^{a}	192.75±3.74^{ab}	182.33±3.75^{c}	0.04
Intestinal length (cm kg^{-1} b.wt.)	92.85±1.86^{b}	99.80±2.69^{a}	93.55±1.93^{b}	86.80±2.40^{c}	0.002

^{a,b,c}Means with at least one common superscript in a row do not differ significantly (p>0.05), G1: Normal energy diet, G2: High energy diet without C_0Q10 supplementation at 20 mg kg^{-1}, G3: High energy diet with C_0Q10 supplementation at 20 mg kg^{-1}, G4: High energy diet with C_0Q10 supplementation at 40 mg kg^{-1}, Normal energy diet: As per breeder's specification, High energy dirt: Normal energy plus 100 kcal

Table 6: Influence of coenzyme Q10 at two levels on the cost effectiveness on broiler production

	Cost of feed per kg (INR)			
Parameters	G1	G2	G3	G4
Pre-starter	32.67	34.10	34.20	34.29
Starter	32.98	34.09	34.19	34.28
Finisher	32.84	34.11	34.21	34.30
Feed intake				
Pre starter	422	374	386	384
Starter	1035	956	963	994
Finisher	1844	1978	1849	1948
Cost of feeding (INR)				
Pre-starter	13.79	12.75	13.20	13.17
Starter	34.13	32.59	33.26	34.08
Finisher	60.56	67.47	63.25	66.82
0-6 weeks body weight gain	2035.6	1976.7	2023.1	1995.9
Feed cost/kg live weight gain* (INR)	53.29±0.12^{c}	57.11±0.05^{a}	54.06±0.13^{b}	57.15±0.10^{a}

^{a,b,c}Means with at least one common superscript in a row do not differ significantly (p>0.05), G1: Normal energy diet, G2: High energy diet without CoQ10 supplementation at 20 mg kg^{-1}, G3: High energy diet with CoQ10 supplementation at 20 mg kg^{-1}, G4: High energy diet with CoQ10 supplementation at 40 mg kg^{-1}, Normal energy diet: As per breeder's specification, High energy dirt: Normal energy plus 100 kcal

The results of serum lipids, minerals, antioxidant activity and muscle cholesterol, muscle CoQ10 and muscle QCI levels are shown in Table 4. Supplementation of CoQ10 in either of the two levels reduced serum triglycerides to the level of normal energy diet and the levels of serum total cholesterol and serum LDL cholesterol were significantly less than the high energy unsupplemented group, but still they were higher than normal energy group. The serum calcium and phosphorus levels were significantly lower in high energy diet group irrespective of level of CoQ10 supplementation. Serum antioxidant activity was higher ($p<0.05$) in both the levels of supplementation. Muscle cholesterol level was significantly reduced on CoQ10 supplementation and the muscle CoQ10 and QCI level higher for the supplemented groups. The level of blood glucose, dressing percentage, giblet weight and its components individually, abdominal fat and spleen weight were not influenced by energy levels or CoQ10 supplementation (Table 5). Normal energy fed birds had lower feed cost per kg live weight gain and it was less by 3.82, 0.77 and 3.86, when compared to high energy diet with 0, 20 and 40 mg kg^{-1} CoQ10, respectively (Table 6).

DISCUSSION

The poor body weight gain and feed efficiency in pre-starter growth phase in high energy diet both without CoQ10 and 40mg CoQ10 kg^{-1} groups since the birds fed with high energy diet were under stress and the CoQ10 supplementation at 20 mg kg^{-1} seems to reduce this effect because of

its antioxidant property. However, these observations are opposite to the findings of Gopi *et al.* (2014a), who reported higher body weight gain with better feed efficiency in high energy diet group, when the birds are reared under ambient temperature. But at 40 mg kg^{-1} CoQ10 supplementation the poor performance is due to very high state of cellular metabolism resulting in higher heat increment and also the production score of CoQ10 supplemented at 20 mg kg^{-1} diet group had comparable production score to that of the normal energy group. Though the overall performance of body weight gain and feed efficiency were not significant, the low production score in unsupplemented and 40 mg kg^{-1} supplemented group was due to the high per cent of mortality in these two groups when compared to normal energy (Table 3). Geng *et al.* (2004a) and Gopi *et al.* (2014b) reported higher incidence of mortality due to leg problem ranging from 0-3 per cent at 40 mg kg^{-1} of diet supplementation.

When compared to normal energy diet, birds fed with high energy unsupplemented diet had higher ($p<0.05$) serum triglycerides, total cholesterol and LDL cholesterol as reported by Shrivastav and Panda (1991) that fat content of whole carcass was significantly increased with increasing energy content of diet. Similarly, reduction in the serum total cholesterol content on CoQ10 supplementation was reported in the study carried out by Omkumar *et al.* (1992), Cicero *et al.* (2005), Modi *et al.* (2006), Jimenez-Santos *et al.* (2014). The CoQ10 was known to decrease the enzymatic activity of 3-hydroxy-3-methylglutaryl coenzyme A reductases (HMGR) in the liver (Honda *et al*., 2010; Kamisoyama *et al*., 2010) involved in the synthesis of cholesterol. Reduction in the serum LDL cholesterol was also reported by Schmelzer *et al.* (2011) due to CoQ10 supplementation and this reduction in the serum LDL cholesterol level was attributed to the action of reduced form of CoQ10 (H_2), which induces characteristic gene expression patterns, which are translated into reduced LDL cholesterol level in humans. The HDL cholesterol was comparable among the treatments. The levels of serum HDL cholesterol and serum triglycerides were not influenced by the CoQ10 supplementation agreeing with the study of Honda *et al.* (2010). The serum lipid profile suggests that even at 20 mg kg^{-1} CoQ10 serum triglycerides, total cholesterol and LDL cholesterol are better metabolized. Serum mineral profile suggests that high energy diets had significantly low calcium and phosphorus levels, when compared to normal energy. Supplementation of CoQ10 at 20 and 40 mg kg^{-1} did not improve the serum calcium and phosphorus levels. The reduced calcium in high energy diet might be due to higher oil incorporation in the ration resulting in formation of calcium soaps and reduced calcium absorption. The decrease in serum calcium level was also observed by Riyazi *et al.* (2011), which might be due the interaction of fatty acid with cations (calcium) resulting in the formation of insoluble calcium soap and reduction in calcium absorption (Gacs and Barltrop, 1977). The low level of serum phosphorus might be due to non-availability of optimum calcium: phosphorus ratio for phosphorus absorption. The serum sodium and potassium levels were not influenced by different treatments. However, earlier studies (Aly, 2012; Gopi *et al*., 2014a) had significantly higher sodium levels upon CoQ10 supplementation.

The serum antioxidant activities were found to be lower in high energy diet with respect to SOD, comparable in terms of reduced glutathione, glutathione peroxidase and vitamin E when compared to normal energy diet. Supplementation of CoQ10 at 20 and 40 mg kg^{-1} increased the levels of SOD, glutathione peroxidase, reduced glutathione and vitamin E over the high energy unsupplemented group. Increase in SOD due to CoQ10 supplementation was also observed by Geng *et al.* (2004b) and Huang *et al.* (2011). The mode of action of CoQ10 on SOD activity is by antagonizing the Nitric Oxide (NO) inactivation; thereby making NO more available for the

biological function leading to extracellular SOD gene-expression (Tiano *et al*., 2007). The reduced glutathione and glutathione peroxidase activity were also found to increase at 20 mg of CoQ10 kg^{-1} as also reported by Lakomkin *et al.* (2005) and Huang *et al.* (2011). The CoQ10 also acts as a primary regenerating antioxidant (Quiles *et al*., 2004). The serum vitamin E level was increased by 20 mg CoQ10 kg^{-1} concurring with the work of Ernster and Dallner (1995). The CoQ10 is closely linked in regenerating the reduced (active) α-tocopherol form of vitamin E (Constantinescu *et al*., 1994). The level of MDA was found to be higher in high energy, than normal energy fed birds. Supplementation of CoQ10 reduced the MDA level to that of normal energy diet. The serum malonaldehyde level was significantly reduced by CoQ10 supplementation at both 20 and 40 mg kg^{-1} of diet, which coincides with results of Geng *et al.* (2004b). This might be due to the protective action on lipid peroxidation in liver mitochondria (Ramirez-Tortosa *et al*., 2008). The above serum antioxidant activity suggests that CoQ10 has role on improving the health status of cells.

Supplementation of CoQ10 only at 20 mg kg^{-1} was found to reduce the muscle cholesterol, increase the muscular CoQ10 content and muscle QCI value, when compared to normal and high energy unsupplemented and 40 mg supplemented diets. The dressing percentage, weight (g kg^{-1} of body weight) of giblet, liver, spleen was not influenced by the experimental diets. The weight of heart and gizzard were comparable among all the treatments. The intestinal length (cm) and the intestinal length (cm kg^{-1} of body weight) of 40 mg CoQ10 kg^{-1} fed birds was significantly less than 0 and 20 mg kg^{-1} supplementation.

The higher cost of feed for live weight gain in high energy diet might have been due to higher environmental temperature wherein the ideal normal energy could have been a better option. Apart from the high cost for per kg live weight gain, the high energy diet had higher degree of leg weakness mortality during the experimental period (Geng *et al*., 2004a).

CONCLUSIONS

In summary, the supplementation of coenzyme Q10 does not have any significant production performance of broiler with high energy diets maintained at the higher environmental temperature, lower relative humidity and higher THI. The CoQ10 supplementation at 20 and 40 mg kg^{-1} of diet improves the lipid metabolism in both serum and muscles and also increases the serum antioxidant status.

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