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Response of duck breeders to dietary L-Carnitine supplementation during summer season

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Abstract: A total number of 300 (225 ducks and 75 drakes) Sudani ducks, 28-wk-old were divided into five groups to investigate the effects of dietary L-carnitine (LC) supplementation on productive, hatching and physiological performance as well as nutrients digestibility coefficients. The results indicated that the productive performance and Semen quality parameters (ejaculate volume, sperms concentration and advanced motility) were significantly improved by LC supplementation (150-450 mg /kg diet) as compared to the control. Hatchability of fertile eggs (%) was significantly improved, while total embryonic mortality was significantly decreased by supplementing 300 and 450 mg LC/kg diet. Supplementing different dietary LC levels resulted in significantly high values of hemoglobin, red and white blood cells count and lymphocyte (L) cells percentage, while it decreased heterophils (H) cells and H/L ratio. Serum albumin, total cholesterol and AST enzyme values were significantly low in ducks fed diets supplemented with LC. Serum triglycerides were significantly the lowest by feeding 300 and 450 mg LC/kg diet. Nutrients digestibility coefficients were significantly improved in drakes fed diet supplemented with 450 mg LC/kg diet. Conclusively, dietary LC supplementation at 300 or 450 mg/kg for duck breeders in summer could improve productive, hatching and physiological performance and nutrients digestibility coefficients.

Key words: Duck breeders, hatchability, laying performance, L-carnitine, semen.

INTRODUCTION

Heat stress during summer season is one of the most important stressors in poultry production (Farghly et al. 2017, 2018), which resulting in generation of enormous free radicals and other reactive oxygen species (ROS) to a level that damage tissue antioxidant defense system and results in oxidative stress (Maini et al. 2007). Duck is one of the poultry species which could be used in solving the lake of animal protein in human nutrition. Sudani ducks is an Egyptian native duck, which like Muscovy; however, their laying performance is inferior to layer-type duck breeders because laying traits are subject to significant confounding factors including genetics and environmental variables (Awad et al. 2013). Duck performance (growth and laying performance, immune suppression, egg quality and high mortality rate, etc.) was depressed as a result of heat stress (Awad et al. 2016, Farghly et al. 2017).

Dietary supplementations are of the useful methods for alleviation of the deleterious impacts

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of the high environmental temperature on poultry performance. Recently, natural feed additives have some characteristics as growth and production enhancers, instead of using synthetic drugs which may have adverse effects on human health. Consequently, there is an increase demand for using natural feed supplementations to overcome the adverse effects of heat stress on poultry performance (Prieto and Campo 2010). In this regard, supplementing antioxidant materials may provide a beneficial effect to prevent stress-induced tissue damages. Antioxidant systems of cells include some natural antioxidants (vitamin E, ascorbic acid, carotenoids, glutathione, ubiquinone and carnitine). Carnitine has acquired benefits in the recent years as a possible feed supplement for enhancing poultry production and also as a substance with possibly ergogenic characteristics for increasing physical performance. Carnitine is a quaternary amine (β-hydroxy γ-trimethylaminobutyrate), which is easily soluble in water, and found in two stereoisomeric forms, D- and L-carnitine (Gulcin 2006). Generally, supplementations are those that help the normal development of physiological functions or that make up for their deficiencies. L-carnitine has antioxidant characteristics, which are fundamental for the transfer of long-chain fatty acid across the inner mitochondria membrane for β–oxidation and eject toxic accumulations of fatty acids from mitochondria, keeping these organelles healthy and functioning at their best (Augustyniak and Skrzydlewska 2009). Dietary L-carnitine supplementation may improve energy production from fatty acids to improve laying production (Al-Hayani 2012), hatching process in chicken embryos and semen production and quality (Al-Daraji and Tahir 2014).

However, there is a paucity of information on the effect of dietary L-carnitine on the laying, hatching and physiological performance as well as nutrients digestibility coefficients of ducks. The current study aimed at investigating the potential effects of dietary L-carnitine supplementation on laying, hatching and physiological performance of Sudani duck breeders under summer conditions.

MATERIALS AND METHODS

BIRDS, EXPERIMENTAL DESIGN AND MANAGEMENT

The present study was carried out at El-Serw Water Fowl Research Station, Animal Production Research Institute (APRI), Agricultural Research Center, Ministry of Agriculture, Egypt, during summer season (first of June to the end of September). The experimental period lasted for 16 weeks; from 28 to 44 weeks of age. All procedures were implemented according to the Local Experimental Animal Care Committee and approved by the ethics of the institutional committee of APRI. Three hundred of Sudani ducks (Egyptian native breed; 225 ducks and 75 drakes), 28-wks-old were taken, weighed (initial body weight average was 1.9 kg) and randomly distributed into five experimental groups, based on their laying rate (20%), in a completely randomized design. Each group contained 60 birds (45 ducks and 15 drakes) and had three equal replicates (15 ducks and 5 drakes each). Each replicate was housed in a pen as 2.3 ducks /m^2 in an open-sided house (24 m× 17 m, equipped with fans and provided with outdoor area of the same dimensions). All birds were placed in the same house. All groups were provided with 16L: 8D light schedule with 10-20 lux/m^2. Throughout the experimental period, feed and fresh water were available all the time. Five graded levels of L-Carnitine (LC) 0, 150, 300, 450 and 600 mg/ kg diet were supplemented to the basal layer diet and fed to the five experimental groups. The ingredients, composition and calculated analysis of the basal experimental diet are shown in Table I. Vaccination and medical schedule were done under a licensed veterinarian.

DATA COLLECTION AND ESTIMATED PARAMETERS PRODUCTIVE PERFORMANCE

Egg number (EN) and feed consumption (FC) were recorded while egg mass was calculated (EM; egg number × average egg weight) for each replicate then averaged and expressed per duck throughout the experimental period (28-44 weeks of age). Laying rate (LR; %) was also calculated (total EN produced/ total ducks* 100) per each replicate. Feed conversion ratio (FCR; g feed/ g eggs) was calculated through the same period. Dead birds were recorded weekly during the experimental period (28 - 44 weeks of age) and then duck viability (%) was calculated through the experimental period.

SEMEN QUALITY TRAITS

Initially, all experimental drakes were selected on the basis of a positive reaction to dorso-abdominal massage for artificial semen collection and then were trained for four weeks (Kammer et al. 1972). After training, three drakes were used from each treatment for artificial collection of semen, and then the cloacal region of each drake was cleaned. Semen was collected weekly during the experimental period, and then semen volume was measured (in milliliter) by using graduated collection plastic tubes. Advanced motility was estimated immediately after semen collection. Sperm concentration was estimated by using an original haemocytometer. The percentage of dead, total abnormalities, and live of sperms were estimated by using nigrocin /eosin staining procedure (Bakst and Cecil 1997).

HATCHING TRAITS AND DUCKLINGS QUALITY

Hatching traits were measured by collecting eggs for 10 consecutive days during the experimental period in three hatches at 33, 37 and 40 wks of age. For each hatch, a total of 750 suitable hatching eggs (150 eggs per each treatment) were collected and stored in a cold-humid area, then set in the 'Econom' incubator and incubated at 37.6 ºC and 65 % relative humidity. Eggs had been turned every 1 h until they transferred to the hatching compartment at the 31st day of incubation. The hatching compartment was kept at 37.0 ºC and 75 % relative humidity until the end of hatching through incubation period.

Fertile eggs and early embryonic mortality were counted at the 10th day of incubation. Then, hatched ducklings and late embryonic mortality (un-hatched eggs with live or dead embryos and dead hatched ducklings) were counted at the end of the incubation period, then, hatchability and

TABLE I
Ingredients, composition and calculated analysis of the basal diet.

Ingredients	%
Yellow corn	65.50
Soy bean meal (44 %)	21.90
Corn gluten (60 %)	3.30
Di-calcium phosphate	1.80
Limestone	6.65
Vit & Min. premix [1]	0.30
NaCl	0.40
DL- Methionine (99 %)	0.15
Total	**100**
Calculated Analysis [2]	
Crude protein %	17.00
ME (Kcal / kg)	2810
Crude fiber %	3.18
Ether extract %	2.75
Calcium %	3.00
Available Phosphorus %	0.45
Lysine (%)	0.79
Methionine (%)	0.45
Meth. + Cyst. (%)	0.75
Na %	0.18

[1]Each 3kg of Vit and Min. premix contains 100 million IU Vit A;2 million IU Vit D3;10 g Vit E; 1 g Vit K_3 ; 1 g Vit B1; 5 g Vit B2 ;10 mg Vit B12; 1.5 g Vit B6; 30 g Niacin; 10 g Pantothenic acid; 1g Folic acid; 50 mg Biotin; 300 g Choline chloride; 50 g Zinc; 4 g Copper; 0.3 g Iodine; 30 g Iron; 0.1 g Selenium; 60g Manganese; 0.1 g Cobalt; and carrier $CaCO_3$ to 3000 g.
[2]According to Feed Composition Tables of Animal and Poultry Feedstuffs used in Egypt (2001).

embryonic mortality percentages were calculated. The hatched ducklings were also weighed and graded according to Tona et al. (2004). Ducklings, at hatch, were classified as a first-grade when they were clean, dry, free of deformities and have bright eyes, while the rest of ducklings were classified as second-grade.

HEMATOLOGICAL PARAMETERS AND BLOOD SERUM CONSTITUENTS OF FEMALES

At 33 wks of age, blood samples were collected (from the wing vein) in vial tubes containing EDTA as anticoagulant from three females per treatment to determine some hematological traits such as hemoglobin concentration and total leukocytes counts. Total white blood cells were counted by haemocytometer, while heterophils (H) and lymphocytes (L) were counted in blood smears by using Wright's stain technique, then H: L ratios were calculated.

At 40 wks of age, blood samples were taken from the wing vein from 3 females per treatment without anticoagulant and kept at room temperature for one hour to clot. Tubes were centrifuged at 3000 rpm for 15 minutes to separate clear serum, and then blood serum was used to determine serum total protein, albumin, triglycerides, total cholesterol, Alanine Aminotransferase (ALT) and Aspartate Aminotransferase (AST) by using commercial kits (purchased from Bio-diagnostic, Egypt) according to the manufacturer's instructions.

NUTRIENTS UTILIZATION COEFFICIENT FOR DRAKES

At 40 weeks of age, nine drakes from each treatment were taken to evaluate the nutrients utilization coefficients. Drakes were fed on their experimental diets for seven days as a preliminary period, followed by three days collection period, where excreta were quantitatively collected. Simultaneously, records of daily feed consumption for each drake were maintained. The daily excreta was voided from every drake in the all treatments, pooled and thoroughly mixed. Then, representative excreta samples were taken and dried immediately for chemical analysis (AOAC 1995). Digestion coefficients were determined for dry and organic matter (DM & OM), crude protein (CP), crude fiber (CF), ether extract (EE) and nitrogen free extract (NFE) as well as total digestible nutrient (TDN) and metabolizable energy were calculated.

STATISTICAL ANALYSIS

Data obtained were statistically analyzed using the general linear model of SAS (2004), as follows: $Y_{ik} = \mu + T_i + e_{ik}$

Where: Y_{ik} = an observation; μ= Overall mean; T= Effect of LC supplementation level; i= (1, 2,.. and 5); and e_{ik}= random error. The significant differences among treatments means were tested by Duncan's multiple range test (Duncan 1955).

RESULTS

PRODUCTIVE PERFORMANCE TRAITS

Dietary LC addition resulted in significant ($P \leq 0.05$) differences in EN, LR and EM among treatments (Table II). Group of ducks fed a diet supplemented by 300 mg LC/ kg followed by those fed a diet supplemented by 150 mg LC/ kg showed the highest values of EN, LR and EM in comparison with their counterparts. Eggs laid by group of ducks fed a diet containing 450 mg LC/ kg were the heaviest when compared with the other groups. Dietary LC supplementation had no significant effect on FC (Table II). Ducks fed diets containing 300 and 450 mg LC/kg had the lowest ($P \leq 0.05$) ratios of feed conversion in comparison with the other groups. Viability (%) was insignificantly increased as increasing LC dietary levels (Table II).

SEMEN QUALITY PARAMETERS

Results of semen parameters are found in Table III. Drakes fed diet containing 450 mg LC/ kg showed

TABLE II
Effect of dietary L-carnitine supplementation on laying performance of Sudani ducks during summer season.

Parameters	L-carnitine level (mg/kg)					SEM	*P* value
	0.0	150	300	450	600		
EN/duck	35.33 [c]	42.54[ab]	44.80[a]	40.47[abc]	39.21[bc]	1.04	0.016
EM/duck, g	2480[b]	3083.1[a]	3253.6[a]	2994.0 [a]	2807.0 [ab]	87.3	0.021
LR, %	31.54[c]	37.98[ab]	40.00[a]	36.13[abc]	35.01[bc]	0.93	0.016
EW, g	70.20 [b]	72.45[ab]	72.62[ab]	73.97 [a]	71.59[ab]	0.40	0.053
FC/duck, kg	14.79	15.14	15.03	14.90	14.88	0.05	0.514
FCR	5.97 [a]	4.91 [b]	4.62 [b]	4.98 [b]	5.30 [ab]	0.15	0.025
Viability, %	93.33	95.67	97.78	97.78	100.0	1.10	0.415

[a,b]means in the same row within each item bearing different superscripts are significantly different ($P \leq 0.05$).
SEM= standard error mean.

significantly (*P≤ 0.05)* the highest percentages of sperms concentration, live sperms and advanced motility and the lowest dead sperms, followed by those fed diet supplemented with 600 mg LC/kg, in comparison with the other groups.

HATCHING TRAITS

Fertility (%), hatchability (%) of fertile eggs, embryonic mortality (%) and duckling's weight at hatch were not significantly different due to dietary LC supplementation (Table IV). First-grade ducklings (%) were significantly improved by 16.49-29.21 % with dietary LC supplementation (150-600 mg/kg), while the second-grade ducklings were significantly decreased by 39.44-71.04 % as compared with the control.

HEMATOLOGICAL PARAMETERS

All studied blood hematological parameters were significantly (*P≤ 0.05)* changed, without specific trend, due to dietary LC supplementation (Table V). Ducks fed a diet supplemented with 450 mg LC/ kg had the highest value of hemoglobin. Group of birds that received dietary 300 mg LC/ kg had the highest count of red cells. Increasing the dietary level of LC was related the increase in white cells counts. Ducks fed diets containing 300 or 450 mg of LC/ kg showed the lowest ratio of H/L in comparison with the other groups.

BLOOD SERUM CONSTITUENTS

All studied serum constituents were significantly changed (*P≤ 0.05)* due to dietary LC supplementation, except of total protein, globulin and A/G ratio (Table V). The highest values of blood serum albumin were recorded by dietary supplementation of 300 and 450 mg LC/kg. Groups of ducks fed diet containing 600 and 450 mg LC/ kg diet had the lowest values (182.2 and 192.6 mg/dl) of total cholesterol in comparison with the other groups. Birds fed a diet containing 450 mg LC/ kg and those fed a diet containing 300 mg LC/ kg showed the lowest averages (130.3 and 131.1 mg/dl) of triglycerides in comparison with their counterparts. Liver AST and AST enzymes were lowered by supplementing different LC levels than the control group.

NUTRIENTS DIGESTIBILITY COEFFICIENTS

Significant impacts were observed in ash and nitrogen retention as well as all nutrients digestibility coefficients due to supplementing different LC levels to the diet (Table VI). Ash retention value was significantly increased by supplementing

TABLE III
Effect of dietary L-carnitine supplementation on semen quality of Sudani drakes during summer season.

Parameters	L-carnitine level (mg/kg)					SEM	*P* value
	0.0	150	300	450	600		
Ejaculate volume (ml)	0.29	0.35	0.38	0.40	0.37	0.02	0.121
Sperms concentration(x10^6/mm)	1.91 [d]	2.23 [c]	2.61 [b]	3.10 [a]	2.61 [b]	0.03	0.0001
Live sperms, %	91.30 [c]	92.00 [bc]	92.75 [b]	94.30 [a]	94.00 [a]	0.33	0.002
Dead sperms, %	8.70 [a]	8.00 [ab]	7.25 [ab]	5.70 [c]	6.00 [bc]	0.33	0.007
Abnormal sperms, %	16.00	14.30	14.30	12.30	13.30	0.50	0.183
Advanced motility , %	73.75 [b]	80.75 [a]	80.15 [a]	80.85 [a]	78.35 [ab]	0.96	0.051

[a,b,c] means in the same row within each item bearing different superscripts are significantly different ($P \leq 0.05$).
SEM= standard error mean.

TABLE IV
Effect of dietary L-carnitine supplementation on hatching traits of Sudani ducks during summer season.

Parameters		L-carnitine level (mg/kg)					SEM	*P* value
		0.0	150	300	450	600		
Fertility, %		83.06	87.52	89.46	89.92	89.50	1.05	0.201
Hatch of fertile eggs, %		70.22	77.02	81.71	80.72	76.50	1.66	0.197
Embryonic mortality, %		29.78	22.98	18.29	19.28	23.50	1.66	0.197
Ducklings quality, %	First-grad	70.51 [b]	82.14 [a]	88.47 [a]	89.80 [a]	91.46 [a]	2.33	0.003
	Second-grad	29.49 [a]	17.86 [b]	11.53 [b]	10.20 [b]	8.54 [b]	2.33	0.003
Duckling weight, g		44.91	45.00	45.67	45.85	45.26	0.23	0.719

[a,b,c]means in the same row within each item bearing different superscripts are significantly different ($P \leq 0.05$).
SEM= standard error mean.

300 up to 600 mg LC/kg diet, while N-retention was significantly higher by adding different LC levels when compared to the control. All nutrients digestibility coefficients were also significantly improved by feeding diet supplemented with 450 mg LC/kg as compared with the control.

DISCUSSION

Egg number per female, in the current work, was high by about 20.41, 26.80 and 14.55 %, while egg mass was significantly heavy by 24.32, 31.19 and 20.73 % for ducks fed diet supplemented with 150, 300 and 450 mg LC/kg, respectively. The significant improvement in egg production (EN or EM) may be due to that dietary LC supplementation increases β-oxidation of fatty acids to adenosine triphosphate, therefore, energy yielding increased by enhancing fatty acid and energy utilization (Neuman et al. 2002). L-carnitine also enhances the oxidation of fatty acids which stimulates estrogen and progesterone biosynthesis by increasing the regeneration of the reducing equivalents necessary for the cholesterol side-chain cleavage reaction, which they work together on growth and maturity of ovarian small follicles and accelerate the process of ovulation (Agarwal and Said 2004). LC is a generator of many amino acids, which ultimately lead to an increase in the proportion of egg production and egg weight by improving the formations and secretion of albumin layers by stimulating lipoprotein precursor's synthesis in the liver and then deposited into oviduct (Al-Daraji and Tahir 2013). The improvement in EM is probably due to the higher metabolic rate in magnum and/or increase in activity of the shell gland, which may improve β-ovomucin secretion when hen's

TABLE V
Effect of dietary L-carnitine supplementation on blood hematological parameters and serum constituents of Sudani ducks during summer season.

Parameters	L-carnitine level (mg/kg)					SEM	*P* value
	0.0	150	300	450	600		
Hematological parameters							
Hemoglobin	12.43 [b]	14.27 [a]	14.60 [a]	14.63 [a]	13.40 [ab]	0.30	0.048
Red cells (x10^6)	4.77 [b]	5.47 [a]	5.83 [a]	5.70 [a]	5.73 [a]	0.13	0.023
White cells (x10^3)	13.93 [b]	18.33 [a]	18.47 [a]	18.53 [a]	18.60 [a]	0.53	0.001
Heterophlis, %	34.33 [a]	23.33 [b]	19.00 [b]	19.67 [b]	19.33 [b]	1.65	0.0001
Lymphocyte, %	65.67 [b]	76.67 [a]	81.00 [a]	80.33 [a]	80.67 [a]	1.65	0.0001
H / L ratio	0.52 [a]	0.31 [b]	0.23 [b]	0.25 [b]	0.24 [b]	0.20	0.0001
Serum constituents							
Total protein (g/l)	5.47	5.72	5.52	5.55	5.56	0.04	0.397
Albumin (g/l)	2.60 [b]	2.81 [a]	2.92 [a]	2.87 [a]	2.79 [a]	0.04	0.024
Globulin (g/l)	2.87	2.91	2.60	2.68	2.77	0.05	0.275
A/G ratio	0.91	0.97	1.12	1.07	1.01	0.03	0.107
Total cholesterol (mg/dl)	240.0 [a]	221.4 [b]	205.5 [c]	192.6 [d]	182.2 [d]	5.67	0.0001
Triglycerides (mg/dl)	154.0 [a]	144.6 [ab]	131.1 [b]	130.3 [b]	139.4 [ab]	3.06	0.044
AST(UI)	30.90 [a]	27.47 [b]	25.73 [b]	26.90 [b]	26.83 [b]	0.52	0.008
ALT(UI)	26.63 [a]	25.17 [ab]	24.63 [b]	25.27 [ab]	22.63 [c]	0.41	0.002

[a,b,c,d] means in the same row within each item bearing different superscripts are significantly different ($P \leq 0.05$).
SEM= standard error mean.

diet supplemented with LC due to that albumen is made from ovomucin and especially β-ovomucin (USDA 2000). Our results are in agreement with those obtained by Al-Hayani (2012) and Awad et al. (2016) who reported that supplementing 300 mg LC /kg diet improved egg number and egg weight of guinea fowl. Kazemi-Fard et al. (2015) reported that supplementing hens' diet with LC had beneficial effects on egg number and mass of laying hens. However, Richter et al. (1998) showed that dietary supplementation of LC (50 up to 500 mg / kg) did not influence egg number and mass of Tetra SL laying hens.

The current findings indicated that ducks fed diet supplemented with different LC levels consumed approximately similar amount of feed. These results may be due to that ducks are able to compensate their FC according to their productivity and energy density of the diet. Our results are in line with those obtained by Parizadian et al. (2011) and Kazemi-Fard et al. (2015) who found that dietary LC supplementation had no significant impact on FC. On the contrary, Awad et al. (2016) indicated that dietary supplementation of 450-600 mg LC/kg, resulted in a low FC in Domyati ducks during 25-41 wks of age. Feed conversion ratio was improved by 17.75, 22.61 and 16.58 % for ducks fed diet supplemented with 150, 300 and 450 mg LC/kg, and this result may attributed to the increase of egg number and mass as well as the improvement in nutrients digestibility coefficient. The current findings are in agreement with those obtained by Al-Hayani (2012), Kazemi-Fard et al. (2015) and Awad et al. (2016) who showed that dietary supplementation of LC improved feed conversion ratio. L-carnitine plays a major role in cells protection from osmotic stress and represents the second line for cell defense against reactive oxygen species and their derivatives as it breaks free-radical chain reactions (termination of

TABLE VI
Effect of dietary L-carnitine supplementation on ash and nitrogen retention and nutrients digestibility coefficient of Sudani ducks during summer season.

Parameters	L-carnitine level (mg/kg)					SEM	*P* value
	0.0	150	300	450	600		
Ash-retained	57.78^{c}	58.34^{c}	64.58^{b}	68.50^{a}	66.850^{ab}	1.22	0.0001
Nitrogen-retained	63.87^{c}	70.37^{b}	71.39^{b}	77.21^{a}	70.76^{b}	1.21	0.0001
Digestibility coefficient, %							
Dry matter	73.5^{c}	73.49^{c}	74.09^{bc}	77.98^{a}	76.46^{ab}	0.57	0.007
Organic matter	75.93^{b}	75.82^{b}	75.55^{b}	79.69^{a}	77.69^{ab}	0.51	0.016
Ether extract	63.20^{b}	65.31^{b}	65.93^{ab}	72.97^{a}	65.76^{ab}	1.23	0.094
Crud fiber	34.91^{c}	39.06^{bc}	38.28^{bc}	47.32^{a}	45.24^{ab}	1.50	0.016
Nitrogen free extract	80.48	80.15	81.86	82.83	82.42	0.42	0.188

^{a,b,c} means in the same row bearing different superscripts are significantly different ($P \leq 0.05$);
SEM= standard error of means.

peroxidation) and prevents undesirable oxidation reactions (Arenas et al. 1998). Similar results were obtained by Awad et al. (2016) who found that viability of Domyati ducks was high by dietary supplementation of LC levels.

The improvement in semen quality (sperms concentration, live sperms and advanced motility or decreasing dead sperms) of drakes fed diet supplemented with LC may be due to their effectiveness as a powerful antioxidant and prevention of the creation of free radicals in the semen as a result of decreasing the quantities of long-chain polyunsaturated fatty acids (PUFA) in the membrane of avian spermatozoa (Agarwal and Said 2004, Al-Daraji and Tahir 2014). L-carnitine supplementation may also plays a major role in increasing follicle-stimulating hormone (FSH), luteinising hormone (LH) and testosterone in the serum of drakes, where FSH is directly responsible for stimulating the process of spermatogenesis, and increasing testis size, Sertoli cell differentiation, and seminiferous tubules size (O'Shaughnessy et al. 2010). LH plays a basic role in the differentiation and maturation of Leydig cells and testosterone production in the interstitial tissue of the testis (Squires 2003) and the high concentration of testosterone enhances growth and maintenance of tests (Jacyno et al. 2007). The present results are in line with those obtained by Baumgartner (2003) who concluded that dietary supplementing with 250 up to 500 mg LC/kg resulted in a significant improvement in sperm count and quality for roosters. Similar findings were also reported in Japanese quails by Sarica et al. (2007) and in ducks by Awad et al. (2016).

Fertility (%), in the present work, was insignificantly improved by 5.37, 7.71, 8.26 and 7.75 % for eggs produced from ducks fed diet supplemented with 150, 300, 450 and 600 mg LC/kg, respectively in the current work and this may be attributed to that dietary LC supplementation increases egg productivity in females and sperm concentration and semen quality in males. Similar results were also found by Sarica et al. (2007) who reported that supplemental dietary LC improved fertility (%) without significant effects in Japanese quail. Awad et al. (2016) indicated that egg fertility of Domyati ducks was significantly improved by dietary LC supplementation. In the current work, hatchability (%) of fertile eggs was insignificantly improved by 9.68, 16.36, 14.95 and 8.94 % for eggs produced from ducks fed diet supplemented

with 150. 300, 450 and 600 mg LC/ kg. Moreover, embryonic mortality (%) was decreased for the same groups by 22.83, 36.58, 35.26 and 21.09 %, respectively. The decrease in embryonic mortality is related to shell breaking strength, which may be reduced by dietary LC supplementation (Corduk and Sarica 2008). Dietary LC may also increases egg yolk LC concentration (Peebles et al. 2007), which plays a beneficial role of embryonic development and newly hatched chicks by increasing energy production which needed for reducing the incidence of late dead embryos, in particularly during the piping process and due to its antioxidant properties which scavenge free radicals production (Zhai et al. 2008). Our findings are similar to those obtained by Al-Daraji and Tahir (2014) and Awad et al. (2016) who revealed that hatchability of fertile eggs was improved, while embryonic mortality (%) was lowered by dietary supplementation of LC in Iraqi and Sudani ducks. First-grade duckling's (%) was significantly improved by 16.49-29.21% by dietary LC supplementation (150-600 mg/kg), while second-grade duckling's was significantly decreased by 39.44-71.04 %. Generally, the embryo has limited capability to synthesize LC during incubation, because gamma-butyrobetaine is limited in embryos due to the low activity of γ-butyrobetaine hydroxylase, although it is required for biosynthesis of L-carnitine (Sato et al. 2006). Awad et al. (2016) got similar results, where supplementing different dietary LC levels to Domyati ducks resulted in a significant improve in ducklings first-grade (%).

Hemoglobin was higher by 14.80-17.70 % in ducks fed diet supplemented with 150-450 mg LC/ kg than those fed the control one. Red and white blood cells counts were higher in the dietary LC supplemented groups by different percentages as compared with the control one. Lymphocytes (%) were increased by 16.75-23.34 %, while heterophils (%) were significantly decreased by 32.04-44.65 % in ducks fed diet supplemented with 150-600 mg LC/kg as compared with the control group, so that, H/L ratio was significantly decreased in those groups. Dietary LC supplementation had a positive effect in enhancing the humoral immune response (Hassan et al. 2011), due to its major role of enhancing antibody response (Deng et al. 2006) and increasing the activity of antioxidant enzymes such as glutathione peroxidase and superoxide dismutase in the blood (Daşkıran et al. 2009). The current results are similar to those obtained by Jameel (2014) and El-Kelawy and ELnaggar (2017) who found that RBCs count and hemoglobin content were increased in chicks fed a diet supplemented with LC. Similarly, Awad et al. (2016) reported that RBCs count and hemoglobin content were increased, while H/L ratio was significantly decreased in Domyati ducks when fed a diet supplemented with 150-600 mg LC/ Kg.

Blood serum constituents of Sudani ducks were estimated to show the metabolic status of ducks and their health as affected by dietary LC supplementation during summer season. Blood serum total cholesterol was significantly decreased by 7.75, 14.38, 19.75 and 24.08 % in ducks fed diet supplemented with 150, 300, 450 and 600 mg LC/kg, respectively, as compared with those fed the control group. The reduction of serum total cholesterol by LC supplementation was attained mostly via a decrease of cholesteryl esters rather than by a decrease in free cholesterol. Moreover, it could be attributed to an increase in biliary sterol excretion or an increase in the conversion of cholesterol to bile acids (Augustyniak and Skrzydlewska 2009). Serum triglycerides were significantly decreased by 15.39 and 14.87 % in ducks fed diet containing 450 and 300 mg LC/kg, respectively. In the current work, dietary supplementation of LC to the ducks may decrease serum triglycerides level as a result of increasing the oxidation of fatty acids by increasing the transportation capacity of fatty acids to inner mitochondrial membrane. As well as, LC increases the activity of lipase and decreases

the activity of lipoprotein lipase, thereby leading to a higher concentration of fatty acid in serum by accelerating hydrolysis of triglycerides to glycerol and fatty acids (Maritza et al. 2006). There are several studies confirmed the beneficial effects of LC in reducing serum lipids, constitutes including total cholesterol and triglycerides (Hassan et al. 2011, Ardekani et al. 2012). The present results are in harmony with the findings of Elgazzar et al. (2012), Fallah and Mirzaei (2016) and Awad et al. (2016) who found that dietary supplementation of LC resulted in a significant decrease in serum total cholesterol and liver enzymes (AST and ALT) as compared to the control group.

In the current findings, all nutrients digestibility coefficient were significantly improved by feeding a diet supplemented with 450 mg LC/kg. LC has the ability of improving the use of dietary nitrogen, whether directly through sparing its precursors (methionine and lysine) for protein biosynthesis and other cellular functions or indirectly by optimizing the balance between essential and non-essential amino acids within the cell (Daşkıran et al. 2009). Furthermore, Ratriyanto et al. (2009) attributed the improvement of nutrients digestibility to the improvements in enzymatic digestion of nutrients, a high absorption capacity of the intestinal epithelium and enhanced fermentation activity of intestinal microflora. The improvement of ash retention which was observed in the current work may be due to that LC improves short-chain fatty acids, originating from microbial fiber fermentation which may promote nutrient absorption due to electrophysiological changes in the enterocytes, resulting in improved mineral absorption and reduced endogenous secretion of minerals (Krishnan et al. 1999). The present results are concordant with those obtained by Awad et al. (2016) who reported that digestion coefficients of organic matter, crude protein and nitrogen free extract as well as ash retention (%) were significantly improved by dietary LC supplementation to Domyati ducks. In contrary with the present result, the latter authors added that digestion coefficients of ether extract and crude fiber were not significantly changed.

In conclusion, based on the present findings, dietary L-carnitine supplementation with 300, 450 or 600 mg/kg for Sudani ducks could be used to maximize and improve the laying performance, hatchability traits, semen quality and nutrients digestibility coefficient, to alleviate the deleterious impacts during summer season. Therefore, dietary L-carnitine supplementation is highly recommended.

AUTHOR CONTRIBUTIONS

Yasser Rizk, Hany Fahim, Malak Beshara and Awad Awad designed and carried out the experimental trial, performed lab analysis, the statistics and tabulated the data. Khalid Mahrose wrote the draft paper and revised and reviewed the manuscript.

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