Research Note

Influence of canthaxanthin on broiler breeder reproduction, chick quality, and performance

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ABSTRACT To investigate the effect of canthaxanthin supplied via a maternal route on the production of both breeder hens and chickens, 270 Chinese Three-Yellow breeder hens were randomly divided into 2 groups consisting of 135 birds each (5 replicates of 27) for study. The breeder hens were fed either a basal diet or the basal diet supplemented with 6 mg of canthaxanthin/kg for 24 wk. At the end of the 24-wk breeder experiment, all hatching eggs laid in 5 consecutive days of each group were collected and incubated. For each breeder group, 100 newly hatched chicks (5 replicates of 20) were reared under environmentally controlled conditions for 21 d. Canthaxanthin supplementation resulted in the following outcomes: an enhancement of the serum total antioxidant capacity (TAC) of breeder hens ($P = 0.029$), a significant increase in the yolk colorimetric score of Roche Yolk Color Fan (RYCF; $P < 0.001$), and a significant improvement of the antioxidant status of the egg yolk ($P < 0.05$). The chicks that hatched from eggs laid by breeder hens fed the canthaxanthin supplementation diet demonstrated a higher pigmentation colorimetric score of RYCF for their shank skin ($P < 0.05$), and the antioxidant capacity of the newly hatched chicks was significantly increased ($P < 0.05$). Both of these positive effects on shank skin pigmentation colorimetric score of RYCF and antioxidant capacity were observed for at least 7 d posthatching, and the chicks that hatched from canthaxanthin-enriched eggs showed a lower mortality (0 vs. 4%) during the first 21 d posthatching. These findings support the hypothesis that canthaxanthin supplementation of the maternal diet enhances the protective capacity of tissues against oxidative stress in vivo, which might be beneficial for poultry producers.

Key words: canthaxanthin, breeder reproduction, chick performance, egg quality, antioxidant activity

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INTRODUCTION

Carotenoids are naturally occurring pigments that are found mainly in plants, algae, and various microorganisms. More than 750 carotenoids have been identified in nature (Britton et al., 2004), and they play important roles in the coloration of many plants, invertebrates, fishes, amphibians, reptiles, and birds because they appear as red, orange, and yellow pigments (Goodwin, 1984). In addition to their importance in signaling secondary sexual characteristics in animals (Griffith et al., 2006), these pigments are also powerful immunostimulants (Lozano, 1994, 2001; Fenoglio et al., 2002). Moreover, carotenoids have been shown to possess antioxidant abilities, which are effective in protecting tissues against oxidative stress (von Schantz et al., 1999; Blount et al., 2000).

Canthaxanthin is an important carotenoid that could be efficiently deposited in egg yolk and further distributed in the chick embryonic tissues (Surai and Speake, 1998). It is one of the most powerful lipid-soluble antioxidants in nature, and it has been identified as a potent free radical scavenger (Palozza and Krinsky, 1992; Zhao et al., 1998; Rengel et al., 2000). Researchers have increasingly focused on the antioxidant characteristics of canthaxanthin, and their studies have shown that the presence of canthaxanthin can potentially and effectively aid in reducing oxidation reactions in several tissues and in chick embryos (for review, see Surai et al., 2001b). In the egg, canthaxanthin is transferred from the yolk to the developing embryo and distributed in many organs and tissues (Llaurado et al., 1997; Surai et al., 2003; Karadas et al., 2005) in which it might help protect the developing bird against oxidative damage, particularly during the sensitive periods of hatching and early posthatch life (Robert et al., 2007). However,

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little information is available in the literature about the effects of canthaxanthin supplementation in maternal diet on production performance and antioxidant status of both the breeder laying hens and their offspring.

In the present study, experiments were conducted in which the diets of Chinese Three-Yellow broiler breeder hens were supplemented with canthaxanthin. The effects of supplementation of canthaxanthin in breeder hens' diet on the reproductive performance (e.g., eggs produced, fertility, and hatchability) of the breeder hens and on the productive performance of their progeny were assessed. It was hypothesized that 1) long-term canthaxanthin supplementation of the diet of laying breeders would enhance the antioxidant status of the breeders and lead to better laying performance; 2) the deposition of canthaxanthin in eggs would improve the activities of antioxidant enzymes that protect the embryo against oxidative stress, which would result in a better hatchability performance; and 3) chickens that hatched from canthaxanthin-enriched eggs would exhibit a better antioxidant status, which would benefit the livability, physical state, and growth performance of the chicks during the posthatch periods.

MATERIALS AND METHODS

Birds and Trial Design

A total of 270 Chinese Three-Yellow broiler breeder hens at 23 wk of age were randomly divided into 2 treatment groups that included 5 replicates of 27 breeder layers each. The control group received a typical commercial diet for Chinese Three-Yellow broiler breeders without canthaxanthin; the other group (referred to as the CX group) received the commercial diet supplemented with 6 mg/kg of canthaxanthin provided in the form of Carophyll Red, which contains 15% canthaxanthin (batch no. V050901; DSM (China) Ltd., Shanghai, P. R. China).

The trial was performed at the Wens Group Fusheng breeding farm (Meishan City, Sichuan, P. R. China). All of the birds were housed in a covered black layer house with manual light control and were inseminated artificially. The rooster diets did not contain canthaxanthin. Feed intake was controlled daily according to standard farm husbandry practices and water was provided for ad libitum consumption. The composition of the breeder diet was shown in Table 1.

The trial was initiated when the hens were 23 wk of age (1 wk of laying), and it was continued until they were 47 wk of age (24 wk of laying). Thus, the total experimental period was 24 wk. At wk 24 of the trial, all hatching eggs (no cracks, no double yolks) laid in 5 consecutive days of each treatment (all of the 5 replicates) were collected, put together, and incubated for 21 d. From each treatment, 100 newly hatched, healthy birds were randomly collected and raised in a single group that contained 5 replicates of 20 birds each. All birds of the 2 groups were raised in environmentally controlled housing with optimal conditions and received the same chick diet (without any additive pigments) from d 1 to 21. The composition of the chick diet was shown in Table 1.

Response Variables

Breeding Performance. Eggs were collected and recorded every day. The total eggs produced per hen housed, hatching eggs per hen housed, egg weight, feed conversion ratio (**FCR**; feed:egg weight, kg:kg), and cumulative mortality (total number of dead birds/initial number of birds × 100%) were calculated weekly.

Table 1. Composition and nutrient levels in the basal diets

Item (% unless noted)	Breeder diet (wk 23–47)	Chick diet (d 1–21)
Ingredient		
Corn grain	66.30	63.49
Wheat grain	0.00	3.20
Wheat middling and red dog	3.00	0.00
Soybean meal	10.50	24.00
Corn gluten meal	4.00	3.20
Fish meal	2.00	2.00
Yeast	3.00	0.00
Vegetable oil	0.48	0.00
Calcium carbonate	7.31	0.96
Calcium hydrogen phosphate	0.67	1.72
Sodium bicarbonate	0.30	0.10
Sodium chloride	0.25	0.26
Choline chloride (50%)	0.15	0.12
L-Lysine monohydrochloride	0.04	0.18
DL-Methionine	0.00	0.16
L-Threonine	0.00	0.06
Enzyme (Kemzyme Dry[1])	0.00	0.04
Ethoxyquin	0.00	0.01
Vitamin–mineral premix[2,3]	2.00	0.50
Calculated nutrient content		
CP[4]	15.21	20.19
ME (MJ/kg)	11.62	12.16
Ether extract	3.96	2.79
Lysine	0.69	1.10
Methionine	0.30	0.49
Methionine + cystine	0.56	0.65
Calcium[4]	3.13	0.92
Nonphytate phosphorus	0.32	0.45
Canthaxanthin (mg/kg)	1.92[5] (8.27)[6]	2.38

[1]Kemin Industries (Zhuhai) Co. Ltd., Zhuhai, P. R. China.

[2]Vitamin–mineral premix provided the following per kilogram of breeder diet: 12,000 IU of vitamin A (retinol acetate), 3,000 IU of vitamin D_3, 10 IU of vitamin E (DL-α-tocopheryl acetate), 2.2 mg of vitamin K_3, 2.2 mg of vitamin B_1, 10 mg of vitamin B_2, 5.5 mg of vitamin B_6, 0.013 mg of vitamin B_{12}, 44 mg of nicotinic acid, 13.2 mg of pantothenic acid, 1.65 mg of folic acid, 0.22 mg of biotin, 120 mg of manganese, 110 mg of zinc, 40 mg of iron, 8 mg of copper, 1.0 mg of iodine, 0.3 mg of selenium.

[3]Vitamin–mineral premix provided the following per kilogram of chick diet: 10,000 IU of vitamin A (retinol acetate), 2,200 IU of vitamin D_3, 20 IU of vitamin E (DL-α-tocopheryl acetate), 1.2 mg of vitamin K_3, 2.0 mg of vitamin B_1, 10 mg of vitamin B_2, 4.0 mg of vitamin B_6, 0.012 mg of vitamin B_{12}, 45 mg of nicotinic acid, 10.0 mg of pantothenic acid, 1.0 mg of folic acid, 0.2 mg of biotin, 150 mg of manganese, 100 mg of zinc, 120 mg of iron, 25 mg of copper, 0.5 mg of iodine, 0.3 mg of selenium.

[4]Determined by analysis.

[5]Content in basal diet.

[6]Content in the basal diet supplemented with 6 mg/kg of canthaxanthin.

At wk 1, 8, 16, and 24 of laying, 15 eggs/treatment (5 replicates of 3 eggs each) were used to determine egg weight, egg yolk ratio (yolk weight:egg weight, g:g), egg shape index (long:short, mm:mm), Haugh units [Haugh units = 100 log (H − 1.7 $W^{0.37}$ + 7.57), in which H = height of albumen (mm) and W = egg weight (g)], and yolk colorimetric score (evaluated by using Roche Yolk Color Fan).

For each treatment, the fertility, hatchability of fertile egg, hatchability of total eggs set, and healthy chicks were recorded every 3 wk. On d 18 of incubation, eggs were candled and clear eggs were opened to determine macroscopic infertility or embryonic mortality; the fertility was expressed as the percentage of fertilized eggs from all incubated eggs. Eggs containing living embryos were transferred to hatcher baskets and placed in a hatcher to continue the incubation process until d 21. The hatchability of fertile egg was expressed as the percentage of chicks obtained from all fertilized eggs, the hatchability of total eggs set was expressed as the percentage of chicks obtained from all incubated eggs, and the healthy chicks were expressed as the percentage among all of the hatched chicks of healthy-looking chicks that were clean and dry, were free of deformities (no skin lesions, well-formed beak, normal conformation of legs), had a completely sealed navel with no yolk sac or residual membrane protruding from the navel area, and had bright eyes (Tona et al., 2004).

Chick Quality and Performance. A total of 100 healthy chicks hatched from the eggs of each breeder treatment were randomly divided into 5 replicates of 20 birds each and weighed at 1 d of age on a replicate basis. Body weight gain, feed intake, FCR (feed:gain, g:g), and cumulative mortality were measured at 7, 14, and 21 d of age on a replicate basis. The Roche Yolk Color Fan (RYCF) was used at 1 and 7 d of age to measure the shank pigmentation of 10 chicks/group (5 replicates of 2 chicks each), and shank pigmentation was evaluated by RYCF scores.

Antioxidant Status in Layers, Eggs, and Chicks. At the end of the layer breeder trial (24 wk of laying), blood samples were randomly collected via the vena brachialis from 10 hens/treatment (5 replicates of 2 hens each) to determine the serum lipid peroxidation in the layers by measuring the levels of malonaldehyde (**MDA**), superoxide dismutase (**SOD**), and the total antioxidant capacity (**TAC**). To reduce the number of samples, the blood samples collected from 2 birds of each replicate were centrifuged; serum was separated and mixed together to generate a single sample and was stored at −20°C for later analysis.

At wk 1, 8, 16, and 24 of laying, 15 eggs/treatment (5 replicates of 3 eggs each) were collected and the yolks were separated to measure MDA, SOD, and TAC. Samples from wk 1, at which time no treatment effect was detected, were used as controls.

On d 1 and 7 of age, blood samples of chicks that hatched from eggs at wk 24 of laying were collected via the jugular vein from 10 birds that were randomly selected for each treatment (5 replicates of 2 birds each), and serum was prepared and stored at −20°C to measure MDA, SOD, and TAC. To obtain sufficient quantities of serum for analysis, the blood samples from two 1-d-old chicks of each replicate were centrifuged; serum was separated and mixed to produce a single sample.

Analysis of Antioxidant Status. Malonaldehyde, which formed as an end product of lipid peroxidation, was treated with thiobarbituric acid to generate a colored product that was measured at 532 nm. Results were expressed as nanomoles per milliliter or gram. The level of MDA was measured by spectrophotometer (model UV-1100, Shanghai Mapada Instruments Co., Shanghai, P. R. China) using commercial MDA Detection Kits (Nanjing Jiancheng Bioengineering Institute, Nanjing, P. R. China). Detailed procedures for the measurements were performed according to the manufacturers' protocols.

The activity of SOD was measured using commercial SOD Detection Kits (Nanjing Jiancheng Bioengineering Institute) with VIS spectrophotometer at a controlled temperature of 25 ± 1°C. The results were detected at a wavelength of 550 nm and the activity values were expressed as units per gram or milliliter. One unit of SOD was defined as the amount of sample that produced an inhibition of 50% under the present assay conditions. Detailed procedures for the measurements were performed according to the manufacturers' protocols.

The TAC was assayed by ferric reducing antioxidant power method (Benzie and Strain, 1999). Ferric reducing antioxidant power assay uses antioxidants as reductants in a redox-linked colorimetric method, employing an easily reduced oxidant system present in stoichiometric excess. The antioxidants are able to reduce Fe^{3+} to Fe^{2+}; TAC was measured by the reaction of phenanthroline and Fe^{2+} using a spectrophotometer at 520 nm. At 37°C, a TAC unit is defined as the amount of antioxidants required to make absorbance increase 0.01 in 1 mL of samples. Commercial TAC Detection Kits (Nanjing Jiancheng Bioengineering Institute) were used and detailed procedures for the measurements were performed according to the manufacturers' protocols.

Statistical Analysis

Results are presented as the means and pooled SEM. The data of the laying performance, egg quality, fertility, hatchability, and antioxidant status of hens and eggs were analyzed by the *t*-test for independent samples using SPSS 13.0 (SPSS Inc., Chicago, IL). The shank pigmentation scores and antioxidant status of hatched chickens were analyzed by 2-way ANOVA using the GLM program. Two-way ANOVA tests with significant *F*-tests for main effects (diet and age) and interaction were further analyzed by the least squares means test. For all statistical analysis, significance was based on $P < 0.05$.

Table 2. Breeding performance of Chinese Three-Yellow broiler breeder hens

Item	Treatment[1]		Pooled SEM	*P*-value
	Control	CX		
Laying performance (average of wk 1–24 of laying)				
Total produced eggs/hen housed (n)	92.02	91.16	1.59	0.828
Total hatching eggs/hen housed (n)	79.68	78.84	0.68	0.858
Egg weight (g)	51.11	51.25	0.14	0.500
Feed conversion ratio (feed:egg, kg:kg)	4.30	4.34	0.13	0.831
Cumulative mortality[2] (%)	2.22	0.74	0.15	0.243
Egg quality[3]				
Egg shape index (long:short)	1.28	1.27	0.01	0.318
Haugh units	73.70	75.20	0.87	0.234
Egg yolk ratio (yolk weight:egg weight)	0.31[b]	0.32[a]	0.01	0.022
Yolk colorimetric score of Roche Yolk Color Fan	8.78[b]	12.91[a]	0.13	<0.001
Fertility and hatchability[4] (%)				
Fertility	87.28	86.46	1.53	0.717
Hatchability of fertile eggs	92.99	94.44	0.64	0.159
Hatchability of total eggs set	81.15	81.69	1.66	0.824
Healthy chicks	97.83	99.17	0.53	0.104

[a,b]Means within a row with different superscripts differ significantly ($P < 0.05$).

[1]The control group received a typical commercial diet for Chinese Three-Yellow broiler breeders without canthaxanthin. The CX group received the commercial diet supplemented with 6 mg/kg of canthaxanthin [provided in the form of Carophyll Red, containing 15% canthaxanthin; DSM (China) Ltd., Shanghai, P. R. China].

[2]The cumulative mortality data were analyzed statistically after being normalized by log (x + 1).

[3]Data are means of 5 replicates of 3 eggs each at wk 8, 16, and 24 of laying.

[4]Data are means of 8 times of incubation.

RESULTS

Breeding Performance

The dietary canthaxanthin supplementation in Chinese Three-Yellow broiler breeder hens for 24 wk did not influence their laying performance and reproductive responses. The addition of canthaxanthin resulted in a significant increase in the yolk colorimetric score of RYCF ($P < 0.001$) and in the egg yolk ratio ($P = 0.022$; Table 2).

Antioxidant Status of Layers and Eggs

The antioxidant status of breeder hens and eggs is shown in Table 3. For breeder hens, with the addition of canthaxanthin, the TAC increased significantly ($P = 0.029$) whereas the MDA level and SOD activity were not significant between the 2 treatments. For eggs, the average yolk TAC at 8, 16, and 24 wk of laying significantly increased ($P < 0.001$) whereas MDA significantly decreased ($P = 0.023$) with the addition of canthaxanthin.

Chick Quality, Performance, and Antioxidant Status

With the addition of canthaxanthin, the BW of 1-d-old newly hatched chicks, weight gain in the first 21 d posthatching, and FCR were not significantly different between the 2 groups (data not shown). The supple-

Table 3. Antioxidant status of breeder hens and eggs

Item[1]	Treatment[2]		Pooled SEM	*P*-value
	Control	CX		
Antioxidant status of breeder hens[3]				
MDA (nmol/mL)	5.15	4.20	0.97	0.520
SOD (U/mL)	256.63	294.86	37.91	0.496
TAC (U/mL)	13.17[b]	16.58[a]	0.91	0.029
Antioxidant status of the egg yolks[4]				
MDA (nmol/g)	139.83[a]	86.92[b]	15.14	0.023
SOD (U/g)	110.92	131.53	9.97	0.155
TAC (U/g)	1.87[b]	3.16[a]	0.22	<0.001

[a,b]Means within a row with different superscripts differ significantly ($P < 0.05$).

[1]MDA = malonaldehyde; SOD = superoxide dismutase; TAC = total antioxidant capacity.

[2]The control group received a typical commercial diet for Chinese Three-Yellow broiler breeders without canthaxanthin. The CX group received the commercial diet supplemented with 6 mg/kg of canthaxanthin [provided in the form of Carophyll Red, containing 15% canthaxanthin; DSM (China) Ltd., Shanghai, P. R. China].

[3]Data are means of 5 replicates of 2 breeder hens each at wk 24 of laying.

[4]Data are means of 5 replicates of 3 eggs each at wk 8, 16, and 24 of laying.

Table 4. Shank pigmentation scores and antioxidant status of chicks[1,2]

Item[3]	1 d of age		7 d of age		Pooled SEM	*P*-value		
	Control	CX	Control	CX		Diet	Age	Diet × age
Shank pigmentation score[4]	6.9[c]	8.1[ab]	7.9[b]	9.6[a]	0.29	<0.001	<0.001	0.401
MDA (nmol/mL)	4.28[a]	2.61[b]	2.74[b]	1.61[c]	0.27	<0.001	<0.001	0.335
SOD (U/mL)	98.39[b]	144.65[a]	144.43[a]	156.66[a]	12.64	0.031	0.032	0.196
TAC (U/mL)	13.82	18.32	14.32	14.73	1.19	0.052	0.211	0.101

[a–c]Means within a row with different superscripts differ significantly ($P < 0.05$).

[1]Data are means of 5 replicates of 2 chicks each.

[2]The control group received a typical commercial diet for Chinese Three-Yellow broiler breeders without canthaxanthin. The CX group received the commercial diet supplemented with 6 mg/kg of canthaxanthin [provided in the form of Carophyll Red, containing 15% canthaxanthin; DSM (China) Ltd., Shanghai, P. R. China].

[3]MDA = malonaldehyde; SOD = superoxide dismutase; TAC = total antioxidant capacity.

[4]Evaluated by using the Roche Yolk Color Fan.

mentation of canthaxanthin in breeder diet reduced the mortality of chicks in the early 21 d posthatching (0 and 4% for the CX and control groups, respectively; data not shown in table). Shank pigmentation scores of 1-d-old chicks significantly increased ($P < 0.05$) in the CX group, and this effect lasted for at least 7 d posthatching ($P < 0.05$; Table 4).

The chick serum antioxidant status was influenced significantly by the treatments. With the addition of canthaxanthin in breeder diet, the MDA levels on d 1 and 7 posthatching significantly decreased ($P < 0.05$), whereas SOD significantly increased on d 1 ($P < 0.05$). However, the levels of SOD on d 7 and TAC on d 1 and 7 posthatching in the chick serum did not significantly differ (Table 4).

DISCUSSION

Many studies have suggested that some carotenoids, such as β-carotene, are beneficial for the productivity of laying females (Damron et al., 1984; Meng and Shan, 2002; Liang et al., 2004). However, to our knowledge, few studies have assessed the productivity (total eggs produced, egg mass, egg weight, FCR, mortality, among others) of laying females that are fed a canthaxanthin-enriched diet.

In the present study, it was hypothesized that potential increases in the antioxidant status of treated laying hens might result in better laying performance in these birds. However, these effects were not observed in the present 24-wk experiment. But the addition of canthaxanthin to the feed of the birds altered the antioxidant condition of the laying hens such that the TAC index increased significantly in the CX group at wk 24 of laying ($P = 0.029$). The important function of carotenoids as antioxidants has been established (Krinsky, 2001; El-Agamey et al., 2004), and a potential benefit exists for the production of laying hens when undergoing a certain degree of stress.

Canthaxanthin can be efficiently deposited and distributed in the ovary, egg yolk, and embryos in both wild and domestic birds (Hencken, 1992; Nys, 2000; Surai et al., 2001a, 2003; Blount et al., 2002). Because canthaxanthin is mainly responsible for orange and red colors in plants and animals, it can be assumed that the phenotype of yolk color in our study, which demonstrated a significant increase from yellow to orange-red in the CX group ($P < 0.001$), can be related to an increase in the canthaxanthin concentration. This result is supported by previous studies in which variations in the carotenoid concentration were assessed in diverse organisms (Blount et al., 2000, 2003; Hill et al., 2002). The egg yolk and embryo are rich in polyunsaturated fatty acids, which cause them to be susceptible to lipid peroxidation (Surai et al., 1999). In the present study, the eggs laid by breeder hens in the CX group demonstrated a better antioxidative status as determined by the significant increase in TAC ($P < 0.001$) and the decrease in MDA ($P = 0.023$). This better antioxidative status of egg yolk might be important for the development of the embryo.

Notably, the shank skin of 1-d-old chicks that hatched from eggs with a high canthaxanthin concentration demonstrated a higher colorimetric score of RYCF, and this effect lasted for at least 7 d posthatching. Previous studies have indicated that canthaxanthin is effectively transferred from the egg yolk to the developing embryo, and thus is distributed in the liver, yolk sac membrane, and plasma during embryonic development. Even after hatching, an increased canthaxanthin concentration was observed in the liver and plasma of chicks that hatched from carotenoid-enriched eggs (Surai and Speake, 1998; Surai et al., 2001a, 2003). In broilers, the pigment was deposited far more effectively in the shank skin than in the other tissues (Zhao et al., 2005). These data clearly show the importance of maternal diets that are enriched in carotenoids with respect to the phenotype of chicks during early postnatal development.

Various antioxidants, such as carotenoids, selenium, and vitamin E, can provide protective effects against lipid peroxidation in embryonic tissues (Surai and Speake, 1998; Surai et al., 1999; Surai, 2000). In the present study, it was demonstrated that a canthaxanthin-enriched maternal diet significantly influenced antioxidant enzyme activities and decreased lipid peroxidant reactions in newly hatched chicks. This positive

effect was observed up to 7 d after hatching. On d 7, the serum MDA levels in chicks from the CX group remained far lower compared with those of chicks from the control group ($P < 0.05$). The cumulative mortality of chicks on d 21 was lower in the CX group than in the control group (0 and 4%, respectively), suggesting that canthaxanthin supplementation of the maternal diet was beneficial for the production of offspring.

In the present study, the chicks of both experimental groups were raised in an environmentally controlled house with optimal temperature, humidity, and ventilation. Therefore, the levels of stress and bacterial and viral infections were low, and the benefits of an enhanced antioxidant status attributable to canthaxanthin supplementation may not have been observed. It could be hypothesized that during acute stresses, the deposition of a high concentration of canthaxanthin in the bodily tissues of birds via a maternal route and the associated enhanced antioxidant status could result in better health conditions and therefore enhanced production performance of the birds (Robert et al., 2007).

In conclusion, the results of this study clearly demonstrate a positive influence of canthaxanthin on several physiological aspects in both breeders and chicks. The potential positive effects of canthaxanthin supplementation of the maternal diet on the performance of both the mothers and their offspring under certain stress conditions require further study. The optimal quantity of supplemented canthaxanthin and potentially optimal combinations with other antioxidants in the diet remain to be determined.

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