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Effects of Dietary Supplementation of Astaxanthin on Production Performance, Egg Quality in Layers and Meat Quality in Finishing Pigs

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ABSTRACT : Two experiments were conducted separately to study the effect of astaxanthin on production performance and egg quality in laying hens and meat quality in finishing pigs. In Experiment 1, four hundred Brown Hy-Line layers, 26 weeks of age, were randomly divided into five treatments according to a single factorial arrangement. Each treatment had four replicates comprising 20 birds each. The dietary treatments were: 0, 0.7, 0.9, 1.1 and 1.3 ppm of astaxanthin fed for 14 days. Then all the birds were fed an astaxanthin-free diet (0 ppm astaxanthin) for an additional 7 days. The results showed that dietary astaxanthin had no significant effect on layer production performance. There was no significant effect ($p>0.05$) on egg weight, yolk height and Haugh unit (HU) with increasing dietary astaxanthin level and increased storage time. Yolk color was linearly increased ($p<0.01$) with the increasing dietary astaxanthin level and significantly decreased with the increasing storage time ($p<0.05$). The TBARS value in yolk decreased linearly ($p<0.05$) with increasing amount of dietary astaxanthin and storage time. When the diets were replaced with the astaxanthin-free feeds, all parameters concerning egg quality decreased with increasing days of measurement, especially the yolk color, and HU significantly decreased ($p<0.05$). In experiment 2, thirty-six barrows (L×Y×D), 107±3.1 kg BW, were randomly divided into three treatments according to a single factorial arrangement. Each treatment had three replicates comprising 4 pigs each. The dietary treatments were: 0, 1.5 and 3.0 ppm of astaxanthin fed for 14 days. The results showed that dietary astaxanthin had no significant effects on production performance. There was a linear effect ($p<0.05$) on dressing percentage, backf.at thickness and loin muscle area with increasing dietary astaxanthin level. There were no significant effects ($p>0.05$) on the TBARS value, drip loss, meat color, marbling and L*, a*, b* values. Cholesterol concentration in meat was not affected by dietary addition of astaxanthin. It could be concluded that astaxanthin supplementation was beneficial to improve egg yolk color; egg quality during storage and it also could improve the meat quality of finishing pigs. (**Key Words :** Astaxanthin, Production Performance, Egg Quality, Meat Quality, Layers, Finishing Pigs)

INTRODUCTION

A new objective is emerging in the feed business towards the use of natural ingredients free from antibiotics, synthetic colors and other chemicals. This is due partly to consumers demand for natural organic products or "green farming" in aquaculture, agriculture, poultry, pig and cattle, and as a result of legislative actions that are eliminating the chemical additives (Gadd, 1997; Sean, 2002; Uuganbayar et al., 2005).

Astaxanthin is one of a group of natural pigments known as carotenoids without vitamin A activity, but it exhibits superior antioxidant properties to beta-carotene in a number of *in vitro* studies (Terao, 1989; Miki, 1991; Palozza and Krinsky 1992; Lawlor and O'Brien 1995; Thompson et al., 1995). Animals cannot synthesize carotenoids by themselves, thus ultimately they must obtain these pigments from the plants and algae.

Astaxanthin serves as a kind of red pigment occurring naturally in a wide variety of living organisms. Most crustaceans, including shrimp, crawfish, crabs and lobster, are tinted red by accumulated astaxanthin. The coloration of fish is often due to astaxanthin; the pink flesh of a healthy wild salmon is a conspicuous example (Skrede et al., 1990; Nickell and Bromage, 1998). In commercial fish and crustacean farms, astaxanthin is commonly added to feeds in order to make up for the lack of a natural dietary source of the pigment (Torrissen et al., 1989; Ingemansson et al., 1993). Astaxanthin provides pigmentation in these farmed animals, and is essential for their proper growth and survival (Storebakken and Goswami, 1996; Jiri, 2000).

Studies showed that astaxanthin increased the yellow pigmentation of skin, feet and beaks in chickens. Broilers

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Table 1. Formula and chemical composition of basal diets for the experiments

Ingredients	Experiment 1 (%)	Experiment 2 (%)
Corn	64.10	68.12
Soybean meal (44%)	17.20	21.08
Limestone	8.00	1.57
Fish meal	4.00	0.00
Wheat bran	3.80	0.00
Tricalcium phosphate (TCP)	1.00	0.30
Animal fat	1.00	3.00
Choline chloride (25%)	0.15	0.01
DL-methionine (50%)	0.20	0.00
Salt	0.25	0.30
Premix [1, 2]	0.30	0.20
Molasses	0.00	3.00
Rice bran	0.00	2.42
Total	100.00	100.00
Chemical composition[3] (%)		
ME (kcal/kg)	2,750	3,300
CP	15.50	15.00
Ca	3.50	0.75
Avail. P	0.35	0.38
Lysine	0.79	0.82
Methionine+cystine	0.64	0.71

[1] Supplied per kilogram of diet for experiment 1: Fe, 70 mg; Cu, 7 mg; Zn, 70 mg; Mn, 70 mg; Se, 0.36 mg; I, 1.4 mg. vitamin A (retinyl acetate), 8,000 IU; cholecalciferol, 2,750 IU; vitamin E (α-tocopheryl acetate), 15 IU; vitamin K_3, 3.0 mg; thiamin, 1.5 mg; riboflavin, 4.0 mg; pantothenic acid, 10 mg; niacin, 25 mg; pyridoxine, 3.0 mg; biotin, 50 mg; folic acid, 0.4 mg; vitamin B_{12}, 10 μg.

[2] Supplied per kilogram of diet for experiment 2: Fe, 100 mg; Cu, 15 mg; Zn, 100 mg; Mn, 25 mg; Se, 0.1 mg; I, 1 mg. vitamin A (retinyl acetate), 10,000 IU; cholecalciferol, 1,000 IU; vitamin E (α-tocopheryl acetate), 30 IU; vitamin K_3, 2.0 mg; thiamin, 2.0 mg; riboflavin, 3.0 mg; pantothenic acid, 15 mg; niacin, 25 mg; pyridoxine, 6.0 mg; biotin, 0.1 mg; folic acid, 1.0 mg; vitamin B_{12}, 0.02 mg.

[3] Calculated values.

on the algae meal diet increased fertility, gained weight faster, had a significantly higher breast muscle weights and utilized feed more efficiently (Inborr, 1998). Similar effects of astaxanthin as natural pigment on yolk color in layers has also been reported (Elwinger et. al., 1997; Lee, et al., 1999). But there is dearth of information on the antioxidant effects of astaxanthin in eggs during storage, and its effect on carcass traits and meat quality in finishing pig. Expecting the positive effects of astaxanthin pigment as an antioxidant, the following layer and pig experiments were conducted to evaluate its effect on the production performance, egg quality of layers and meat quality of finishing pigs.

MATERIALS AND METHODS

Experiment 1

Experimental animals and diets : Hy-Line Brown layers (n = 400; 26-wk-old) was randomly divided into five treatments according to a single factorial arrangement. Each treatment had four replicates with 20 birds each. Hens were caged individually with the cage size as 0.2×0.2 m. The photoperiod was set at 17L:7D throughout the 21 days experiment. The layers were kept under a temperature of 25±5°C. They were fed corn-soybean basal diet that was formulated to meet the nutrient requirements of layers (NRC, 1994). Diets were supplemented with 5 levels (0, 0.7, 0.9, 1.1 and 1.3 ppm) of astaxanthin for the first 14 days, then all birds were placed on the astaxanthin-free diet (0 ppm astaxanthin) for additional 7 days. Compositions of the experimental diet were shown in Table 1. Feed and water were provided *ad libitum*.

Parameters measured : Daily egg production and egg weight were recorded. Feed consumption was measured weekly during the 14 days experiment. Laying rate and feed efficiency (kilograms of feed needed to produce a kilogram of eggs) were calculated at the end of the experiment. At 14th day, ten eggs were collected from each replicate for analysis. Further ten eggs were collected at 2-day interval from each replicate at the 15th day, 17th day, 19th day, 21st day during last week for egg quality analysis. Five eggs were analyzed immediately and the other five were stored at 30°C and analyzed one week later.

Analysis of egg quality : Yolk color was measured with Roche Yolk Color Fan (RYCF) (Dotterfarbächer Eventail colorimétrique Abanico colorimétrico, USA). Its color values denote the color intensity from 1 to 14 according to the degree of yolk color. Yolk height was measured with vernier callipers in the centre of yolk. Haugh units (HU) were calculated according to formula (Eisen et al., 1962) based on the height of albumen as determined using vernier callipers.

Lipid oxidation analysis : Thio-barbituric acid reactive substances (TBARS) were measured as milligrams of malonaldehyde (MDA/kg). Eggs collected at the 14th day were analyzed for lipid oxidation. The measurements on eggs were carried out immediately or stored at 30°C in the oven for one week after the day of collection. Exactly 10 g of yolk was used to determine the thio-barbituric acid reactive substances (TBARS) as milligrams of malonaldehyde (MDA/kg) according to Tarladgis et al. (1960), Rhee (1978), and Marshall et al. (1994).

Experiment 2

Experimental animals and diets : Barrows (n = 36; L×Y×D), weighing 107±3.1 kg, were randomly assigned according to a single factorial arrangement. Each treatment had three replicates comprising 4 pigs each. Pigs were housed in a total confinement, slatted-floor facility in 3 adjacent pens (3.0×3.0 m). Treatments included a control diet (0 ppm) and two astaxanthin supplemental levels, 1.5 ppm and 3.0 ppm in the diets. Pigs were kept on experimental diets for two weeks until about 120±5 kg of

Table 2. Effect of astaxanthin on production performance of layers

	Astaxanthin (ppm)					SEM[1]	p value	
	0	0.7	0.9	1.1	1.3		Linear	Quadratic
Feed intake (g/hen/d)	105.37	104.78	103.88	106.34	103.90	0.67	0.8392	0.3509
Laying rate (%)	82.32	82.10	78.75	82.77	83.20	0.76	0.6486	0.2231
Feed efficiency (kg:kg)	2.27	2.19	2.10	2.22	2.23	0.03	0.4799	0.2231

[1] Standard error of means.

Table 3. Effect of astaxanthin on growth performance of finishing pigs

	Astaxanthin (ppm)			SEM[1]	p value	
	0	1.5	3.0		Linear	Quadratic
ADG (g)	715	724	690	10.54	0.3751	0.3782
ADFI (g)	2,452	2,425	2,457	67.69	0.9800	0.8643
FCR	3.43	3.37	3.59	0.07	0.4730	0.3623

[1] Standard error of means.

BW, after that they were humanely slaughtered. Compositions of the experimental diet were shown in Table 1. Feed and water were provided *ad libitum*.

Parameters measured : Average daily gain, average daily feed intake, and feed conversion ratio were calculated at the end of the feeding trial. At the last day of the experiment, pigs were weighed just before immobilization, then exsanguinated, scalded, dehaired, decapitated, eviscerated, halved and inspected. All loins were cut into 2.54-cm-thick chops. Chops were deboned and trimmed to 0.64 cm of subcutaneous fat, and then chops were paired and placed in vacuum bags. The vacuum packages were assigned to 5 or 10 day of cold (4°C) storage. From each loin three 1.27-cm chops were also cut for the measurements of lipid oxidation (TBARS) and cholesterol. These chops were stored in vacuum bags under the same conditions as the 2.54-cm chops.

Lipid oxidation analysis : Samples of each chop were measured for lipid oxidation at 0, 5 and 10 day of storage. Lipid oxidation of loin chops was measured by TBARS analysis as described previously by Sinnhubber and Yu (1977).

Carcass traits : Procedures for carcass traits evaluation were according to the methods described by Matthews et al. (1998). Dressing percentage was determined by the following equation: (hot carcass weight/final live weight) ×100. Live weight was monitored the day before slaughter. Backfat thickness was determined at the 10th rib, at three quarters of the lateral length of the loin muscle perpendicular. At 5 or 10 day postmortem, the left longissmuss thoracis at lumborum (rib side) from each carcass was removed. Chops were removed from the longissmuss thoracis at lumborum starting at the 11th rib location and continued towards the caudal end for drip loss (one 2.5-cm thick chop) determination. At 24 h postmortem, whole loins were subjectively evaluated for color, marbling between the 10th and 11th rib face according to a 5-point descriptive scale by the National Pork Producers Council Quality Standards (NPPC, 1999). In addition, L*, a* and b* color values were measured using color difference meter (Yasuda Seiko Co., CR-310, Minolta, Japan) at 0, 5 or 10 day postmortem.

Cholesterol in meat : Muscle (semimembranosus) samples were frozen in liquid N and stored at -30°C until they were analyzed for total cholesterol concentration, high-density lipoprotein (HDL) and low-density lipoprotein (LDL). Total muscle cholesterol content was determined with the enzymatic method of Allain et al. (1974) as modified by Salé et al. (1984). HDL was determined by using HDL cholesterol assay kit (Sigma-Aldrich, Seoul, Korea).

Statistical analyses

All data were analyzed by ANOVA using the GLM procedure of SAS (SAS Institute, 1996) as a completely randomized design. The linear and quadratic trends were tested for the supplemented astaxanthin levels. All statements of significance were based on probability $p<0.05$, unless otherwise noted.

RESULTS AND DISCUSSION

Production performance

The effects of dietary astaxanthin on layers and pig's performance are shown in Table 2 and 3, respectively

Dietary astaxanthin supplementation had no significant effects on layers performance ($p>0.05$). The present findings were in accordance with that reported by Lorenz (1999) and Ross et al. (1994), where *Haematococcus* alage meal or *Spirulina* supplementation of diets had no adverse

Table 4. Effect of astaxanthin on egg quality and TBARS (mg/kg) in yolk of layers measured at different storage time

	Time	Astaxanthin, ppm					SEM[1]	p value	
		0	0.7	0.9	1.1	1.3		Linear	Quadratic
Egg weight (g)	0 wk[2]	56.75	61.13	58.86	57.83	63.16	1.09	0.9904	0.2745
	1 wk	56.97	59.07	57.91	58.34	62.87	1.12	0.8484	0.7492
Yolk color	0 wk	7.75	11.00	11.50	12.25	13.00	0.46	0.0001	0.0308
	1 wk	7.00	8.50	10.50	12.50	13.00	0.54	0.0001	0.4755
Yolk height (mm)	0 wk	6.09	7.02	6.48	6.53	6.95	0.27	0.8666	0.5127
	1 wk	4.69	4.61	4.09	4.86	4.80	0.20	0.9026	0.3920
Haugh unit	0 wk	78.05	75.58	79.68	80.35	81.98	2.24	0.6233	0.7780
	1 wk	58.65	63.50	62.55	67.33	71.13	2.22	0.3559	0.9946
TBARS (mg/kg)	0 wk	0.68	0.67	0.62	0.61	0.51	0.05	0.7129	0.9874
	1 wk	6.53	4.85	4.16	3.65	3.68	0.94	0.4370	0.8193

[1] Standard error of means. [2] Storage week after collecting eggs.

Table 5. Effect of astaxanthin on carcass traits of finishing pigs

		Astaxanthin (ppm)			SEM[1]	p value	
		0	1.5	3.0		Linear	Quadratic
Dressing percentage		70.55	72.71	75.01	0.73	0.0040	0.9373
Backfat thickness (mm)		29.00	23.33	22.00	1.15	0.0011	0.0795
Loin muscle area (cm^2)		54.00	62.92	68.58	2.84	0.0340	0.7370
Meat color score		1.83	1.92	2.33	0.20	0.3680	0.7208
Marbling score		2.17	1.83	2.25	0.22	0.8936	0.4956
TBARS (mg/kg)							
	0[2]	1.12	1.08	1.06	0.04	0.6096	0.9023
	5	2.81	2.56	2.42	0.15	0.3511	0.8622
	10	3.28	3.10	3.30	0.09	0.9339	0.3640
Drip loss (%)							
	5	8.14	8.27	7.20	0.34	0.2873	0.4816
	10	9.93	9.85	8.14	0.55	0.1975	0.5304
Meat color							
L	0	55.74	54.41	55.92	0.66	0.9139	0.3243
	5	57.51	55.83	58.60	0.58	0.4333	0.0723
	10	55.12	53.98	56.58	0.55	0.2692	0.1065
a	0	17.43	18.16	17.74	0.14	0.3648	0.0528
	5	17.65	18.34	17.45	0.58	0.5235	0.0064
	10	15.30	14.73	14.36	0.29	0.1996	0.8703
b	0	6.21	6.31	6.13	0.19	0.8621	0.7277
	5	11.31	10.88	11.09	0.09	0.3224	0.0977
	10	7.03	6.64	7.45	0.20	0.3779	0.1546

[1] Standard error of means. [2] Day after postmortem.

effect on egg production, feed efficiency and laying rate. However, Inborr (1998) found that the broilers on the *Haematococcus* alage meal diet gained weight faster, had a significantly ($p<0.05$) higher breast muscle weights and utilized feed more efficiently compared with the control group. There was no effect on the pig's performance by astaxanthin addition in the diets in the present study.

Egg quality

For experiment 1, the effects of dietary astaxanthin on egg weight, yolk color, yolk height and HU, are shown in Table 4. There was no significant effect on egg weight with the increased dietary astaxanthin and with increasing storage time ($p>0.05$). Yolk height and HU also had not been significantly affected by the astaxanthin ($p>0.05$). There was a little increment in yolk height and HU with the increasing dietary astaxanthin, although it could not achieve linear relationship, which was consistent with the results of Inborr (1998), Ross and Dominy (1990).

The degree of yolk color preferred by consumers varies widely throughout the world; however, deeper hues bring significant premiums in most markets. The bakery and food processing industry prefer darker colored yolks rather than adding artificial coloring agents. The yolk color is a very

important index of egg quality. In the present study, yolk color was significantly increased linearly with the increasing dietary astaxanthin and significantly decreased with the increasing storage time ($p<0.05$). Elwinger et al. (1997) found that the egg yolk color pigments reached steady states of 5.8, 7.9, 9.4, 10.1 and 11.8 on the color scale, respectively, for the experimental diets supplemented with 0.5, 1.0, 1.5, 2.0 and 3.0 ppm astaxanthin. Lee et al. (1999) found that astaxanthin produced a linear increment in egg yolk coloration compared with eggs from layers fed astaxanthin-free diet. A report by Mammershoj (1995) was also in agreement with our findings, where they fed astaxanthin to layers resulting in a significant increment of egg color.

Carcass traits

In experiment 2, dressing percentage ($p<0.05$) and loin muscle area ($p<0.05$) increased linearly and backfat thickness decreased linearly ($p<0.05$) with the increasing dietary astaxanthin. Drip loss measured at 5th or 10th day after postmortem showed no difference among treatments. Measurements of color, marbling, and the L*, a*, and b* values at 0, 5th or 10th day after postmortem are shown in Table 5. Generally, dietary astaxanthin had no significant effects on meat color ($p>0.05$). The 3.0 ppm astaxanthin treatment had a higher color value of all parameters, though it could not achieve statistical significance.

Lipid oxidation

TBARS is an index of lipid peroxidation and oxidative stress. The TBARS value, expressed as malondialdehyde (MDA), is a good index reflecting the degree of oxidation (Lohakare et al., 2004). It is considered that the higher the TBARS value, the more oxidation of lipids has taken place.

In Experiment 1, the TBARS values linearly decreased with the increasing amount of dietary astaxanthin in each storage time (Table 4). The TBARS values in yolk were higher in the control group compared with experimental treatments. The values measured after one week of storage at 30°C were higher in all groups, and the TBARS value in the control group without astaxanthin was also higher than astaxanthin added groups, which was an indication that oxidation had been progressed and astaxanthin had played an anti-oxidative role in the lipid oxidative process in the yolk.

In Experiment 2, the TBARS value in meat was measured at 0, 5th or 10th day after postmortem (Table 5). Although it could not achieve linear relationship, the TBARS values in meat decreased with the increasing astaxanthin addition in diets. Astaxanthin might have improved the lipid stability through increasing superoxide dismutase, catalase and glutathione peroxidase enzyme activity (Kobayashi, et al. 1997; Kurashige, et al., 1990; Palozza and Krinsky, 1992). Antioxidant function of astaxanthin persists for a long time delaying the onset of oxidation reactions in egg yolk and meat. The eggs from 0 ppm astaxanthin treatment stored for one week had higher TBARS than those with added astaxanthin, especially 1.3 ppm astaxanthin treatment. Thus, it could be stated that the supplementation of dietary astaxanthin has a beneficial role in egg storage by preventing it from getting deteriorated. The present findings were in accordance with that reported by Terao (1989), where supplementation of dietary astaxanthin produced higher levels of phosphatidylcholine

Table 6. Egg quality of layers without astaxanthin in diet measured at different time during the last week[1]

	Time (day)	Astaxanthin (ppm)					SEM[2]	p value	
		0	0.7	0.9	1.1	1.3		Linear	Quadratic
Egg weight (g)	15th	60.45	63.35	62.42	63.11	62.96	0.64	0.3569	0.4606
	17th	57.88	57.77	61.09	61.81	58.73	0.97	0.1235	0.8539
	19th	57.93	58.26	59.55	58.75	57.72	0.73	0.5987	0.7474
	21st	56.97	61.21	59.88	59.70	61.56	0.75	0.4705	0.2107
Yolk color	15th	8.50	11.17	11.50	11.33	12.83	0.32	0.0011	0.0083
	17th	7.33	10.17	10.83	11.17	12.67	0.39	0.0001	0.0249
	19th	6.83	8.60	8.67	9.00	9.17	0.27	0.0154	0.1981
	21st	5.50	8.33	8.17	8.00	9.83	0.29	0.0001	0.0001
Yolk height (mm)	15th	11.61	11.42	11.39	11.65	10.92	0.21	0.9676	0.6592
	17th	10.38	10.31	9.30	9.32	9.82	0.21	0.0204	0.9162
	19th	9.17	10.40	9.65	9.95	8.97	0.19	0.5253	0.2541
	21st	7.77	10.22	9.61	9.45	8.59	0.30	0.1958	0.0580
Haugh unit	15th	108.50	106.38	106.02	107.00	103.53	1.19	0.7035	0.5801
	17th	101.08	101.08	96.08	96.47	98.77	0.84	0.0186	0.9137
	19th	97.90	101.88	97.42	98.65	94.85	0.77	0.5540	0.3853
	21st	88.50	99.43	96.18	99.05	95.70	1.50	0.0783	0.3222

[1] Eggs were collected during the last week at 2-day interval starting at 3rd week. For each parameter 4 times measurement was carried out. For each collection, 5 eggs were collected from each replicate.

[2] Standard error of means.

Table 7. Effect of astaxanthin on cholesterol concentration in meat of finishing pigs

	Astaxanthin, ppm			SEM[1]	p value	
	0	1.5	3.0		Linear	Quadratic
Cholesterol (mg/100 g)						
Total	50.56	47.39	48.68	0.78	0.3281	0.1951
HDL	33.36	31.03	31.61	0.69	0.3351	0.3533
LDL	17.20	16.36	17.07	0.44	0.9155	0.4749

[1] Standard error of means.

hydroperoxide (PC-OOH) and malondialdehyde (MDA) in plasma in broilers.

Egg quality without astaxanthin in diet

The results of egg quality without astaxanthin in diet are shown in Table 6. When the layers were returned to the astaxanthin-free feeds, all parameters were decreased with the increase in time, especially the yolk color and HU ($p<0.05$). These findings of our experiment are in accordance with Anderson et al. (1991), where *Spirulina* was added at concentrations of 0.25, 0.5, 1, 2 and 4% of diet for 21 days, then returned to the carotenoid-free feeds (without *Spirulina*), the egg yolks gradually returned back to the control levels of 2 on the color scale. Avila and Cuca (1974) found that there was linear relationship between dietary *Spirulina* concentrations and egg yolk pigmentation. Diets containing *Spirulina* produced significantly darker yolks than diets containing the same carotenoid concentration from marigold meal in White Leghorn hens. Therefore, it once again suggested that the supplementation of dietary astaxanthin has a beneficial role in enhancing yolk color and egg quality.

Cholesterol concentration in meat

The effects of dietary astaxanthin on cholesterol concentration in meat are presented in Table 7. The concentrations of cholesterol, HDL, and LDL in meat from astaxanthin fed animals were lower compared with control, although it could not reach significance. Nakano et al. (1995, 1999) reported that in rainbow trout fed oxidized oil, astaxanthin supplementation reduced high levels of triglyceride and total cholesterol in the blood, and increased defenses against oxidative stress. Astaxanthin was provided daily over 2 weeks to humans using an astaxanthin-containing drink at 3.6, 7.2, and 14.4 mg/day, and no ill effects were reported at any dose, and in fact an antioxidant effect on serum LDL was observed, with LDL oxidation progressively decreased with increasing doses of astaxanthin (Miki et al., 1998). All the findings were in accordance with our present study.

Overall we concluded that supplementation of dietary astaxanthin could be beneficial to layers to improve egg yolk color and the keeping quality of eggs. Also dietary astaxanthin improved the carcass traits and meat quality of finishing pigs in the present study.

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