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Nutritional impacts of using graded levels of dietary linoleic acid on egg production, egg quality, and yolk fatty acid profile of laying ducks

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ABSTRACT

There is an increased interest among poultry nutritionists to increase the linoleic acid (LA) content of the egg, which possesses many benefits for human health. This fatty acid must be provided by the diet as the bird's body cannot synthesise it. The present study evaluated the influence of different levels of dietary LA on the productive performance, egg quality and yolk lipid profile of Longyan laying ducks. In total, 900 Longyan female laying ducks aged 24 weeks were assigned to six dietary treatments, each containing 6 replicates of 25 ducks. The six dietary treatments contained six incremental levels of LA (analysed content: 0.36, 0.66, 0.80, 1.07, 1.28, and 1.45%) and the experimental diets were offered for the following 20 weeks. The results showed that different supplemental levels of dietary LA had no effects on egg production traits, concentrations of plasma cholesterol and triglycerides, or low or high-density lipoprotein cholesterol ($p > .05$). There was a linear increase in yolk colour ($p < .001$) and yolk cholesterol ($p < .005$) with increasing dietary LA. With increased intake of LA, the yolk content in C18:1, C20:1 and total monounsaturated fatty acids decreased linearly (all $p < .005$), but the concentrations of C18:2, C18:3, C20:2, C20:3, C20:4, C20:6, and total polyunsaturated fatty acids were linearly increased ($p < .008$ to $< .0001$). The results of the present work show that LA dietary supplementation of Longyan duck layers positively modified the yolk fatty acid profile, increased the yolk cholesterol, and enhanced the yolk colour.

HIGHLIGHTS

- Linoleic acid (LA) is an essential fatty acid that must be added to the poultry diet.
- This study evaluated six dietary levels of linoleic acid in laying ducks.
- LA dietary supplementation modified yolk colour, cholesterol and fatty acid profile.

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Introduction

Linoleic acid (C18:2n-6) (**LA**) is an essential fatty acid that must be provided by the diet because it cannot be synthesised by the animal body; it is a common constituent of liquid vegetable lipids. Linoleic acid is a very important nutrient for animals as many studies have shown that it promotes growth, lipid metabolism, arachidonate synthesis, and enhances body immunity. Hopkins and Nesheim (1967) noted that LA deficiency, compared to adequate levels, in chicks resulted in reduced growth performance and elevated hepatic fat content. Menge (1970) suggested that Leghorn hens fed a purified diet required approximately 2% dietary LA (18:2), supplied by corn oil, for optimal egg production. Sijben et al. (2000) concluded that LA enrichment of the diet of growing laying hens (pullets) has an antigen-dependent divergent effect on the antibody response. Shannon and Whitehead (1974) and Whitehead (1984) found that 1.0% LA is

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adequate to maximise egg size and productivity of laying hens, whereas using levels greater than 2% LA led to advantages in egg weight (Scragg et al. 1987). Several related studies have been implemented with hens but none for laying ducks that possess different biological charecteristics. For example, the crop of hens acts as a storage organ, whereas that of ducks is considered as a distensible gullet. There are differences between ducks and hens in the laying time and ovipository cycle, which make it difficult to compare the findings between hens and ducks. It is hypothesised that testing graded levels of dietary LA for laying ducks is expected to contribute in optimising egg production and achieving a higher value consumer product with enhanced content of PUFA. The present study is a preliminary investigation of the effect of varying dietary LA on laying performance, egg quality, and yolk fatty acid profiles in laying ducks.

Materials and methods

Experimental design, animals and housing

Longyan laying ducks ($n = 900$), with comparable body weight (1.20 ± 0.07 kg) at 24 weeks of age, were randomly allocated into six treatment groups, each group containing six pen replicates of 25 birds (pens were 3×4 m indoor, 3×5 m outdoor, and 3×5 m fish pond). Each replicate was provided with the diets for 20 weeks; the daily allowance of feed was the maximum the ducks would consume without leaving refusals. The basal diet was a wheat-soybean-based formulation (Table 1) meeting the nutrient requirements of laying ducks, based on work from this group (Xia et al. 2014; Xia, Abouelezz, et al. 2019; Xia, Chen, et al. 2019). Soybean oil and sodium palmate (saponified palm oil) were added to the diets to provide six graded levels of linoleic acid (LA) (Analysed content: 0.36, 0.66, 0.80, 1.07, 1.28, and 1.45%) with minor or no change in the other ingredients or nutrients, according to Safaa et al. (2008). Fatty acid analyses, conducted with the method of gas chromatography of methyl esters, showed 49.9% LA content in soybean oil and 10.2% in the sodium palmate. Determination of linoleic acid content in the dietary treatments, soybean oil and sodium palmate are described next in Section 'Fatty acid composition and linoleic acid content of feed'. The ducks were exposed to 15 h natural and incandescent lighting (10 lux) and 9 h of dark throughout the experimental period. After 20 weeks of feeding, two birds with a body weight within the average of each replicate were selected and 5-mL heparinised blood samples were collected from the jugular vein.

Table 1. Composition and nutrient levels (%) of experimental diets (air-dry basis) of laying ducks aged 24–44 weeks.

	Linoleic acid, %					
Ingredients	0.36	0.66	0.80	1.07	1.28	1.45
Wheat	62.8	57.9	57.2	56.9	56.3	55.8
Soybean meal	17.53	18.19	18.10	18.10	18.02	18.00
Limestone	8.50	8.50	8.50	8.50	8.50	8.50
Glucose	5.00	5.00	5.00	5.00	5.00	5.00
Alfalfa meal	3.20	5.47	6.25	6.55	7.23	7.71
Calcium hydrogen phosphate	1.28	1.28	1.28	1.28	1.28	1.28
Premix[a]	1	1	1	1	1	1
Sodium chloride	0.30	0.30	0.30	0.30	0.30	0.30
L-Lysine·HCl	0.24	0.21	0.21	0.21	0.21	0.21
DL-Methionine	0.15	0.15	0.15	0.15	0.15	0.15
Soybean Oil	0.00	0.00	0.49	1.01	1.53	2.04
Sodium palmate	0.00	2.00	1.51	0.99	0.47	
Total	100	100	100	100	100	100
Calculated analysis						
AME, MJ/kg	10.46	10.46	10.46	10.46	10.46	10.46
Crude protein[b], %	17.37	17.57	17.21	17.34	17.02	17.32
Total lysine, %	0.87	0.87	0.87	0.87	0.87	0.87
Total methionine, %	0.42	0.42	0.42	0.42	0.42	0.42
Linoleic acid[b], %	0.36	0.66	0.80	1.07	1.28	1.45
Calcium, %	3.60	3.60	3.60	3.60	3.60	3.60
Total phosphorus, %	0.59	0.59	0.59	0.59	0.59	0.58
Available phosphorus, %	0.35	0.35	0.35	0.35	0.35	0.35

[a]Provided the following (per kg of diet): VA 12,000 U, VD_3 2000 U, VE 38.7 U, VK_3 1.0 mg, VB_1 3.0 mg, VB_2 9.6 mg, VB_6 6.0 mg, VB_{12} 0.03 mg, Choline chloride 1000 mg, D-pantothenic acid 28.5 mg, Folic acid 0.6 mg, Biotin 0.15 mg, Fe 50 mg, Cu 10 mg, Mn 90 mg, Zn 90 mg, I 0.50 mg, Se 0.40 mg. [b]Analysed value.
Abbreviation. AME: apparent metabolisable energy.

Productive performance

After a seven day adaptation period on the experimental diets, feed intake, egg number, and individual egg weights were daily recorded on a per replicate basis during the following 20 weeks. Egg production rate (%) [(total egg number/number of birds) x 100], daily egg mass (total daily egg weight/number of birds) (g egg/bird/day), daily feed intake [(Added feed – refused feed)/number of birds], and feed conversion ratio (FCR, g feed/g egg) were daily calculated from these data and averaged for the entire experimental period on a per replicate basis.

Plasma analysis

Freshly collected blood samples (two/replicate), taken from the wing vein into heparinised tubes, were centrifuged (1200 × *g*) at 4 °C for 10 min and plasma was stored at −20 °C. The colour of the quinone compound produced by combining CHO/TG with the working fluid in the kit (Nanjing Jiancheng Bioeng. Inst., Nanjing, China) is directly proportional to the content of CHO/TG in the plasma, the combination of HDL-C and working solutions in the kit (Nanjing

Table 2. Effect of different concentrations of dietary linoleic acid on productive performance of laying ducks aged 24–44 weeks.

	Linoleic acid, %							
Variables	0.36	0.66	0.80	1.07	1.28	1.45	SEM	*p*-Value
Egg production, %	87.29	90.17	88.67	87.27	88.36	88.21	1.46	.75
Egg weight, g	65.53	65.60	65.62	65.39	64.87	64.98	0.34	.48
Feed intake, g/d	167.00	167.00	167.00	167.00	167.00	167.00	0.00	1.00
Egg yield, g/d	57.17	59.12	58.16	57.03	57.30	57.35	1.02	.68
Feed conversion ratio, g feed/g egg	2.96	2.85	2.90	2.97	2.94	2.95	0.06	.77

Jiancheng Bioeng. Inst., Nanjing, China) produces a red-purple reaction, LDL-C reacts with the R1 and R2 working solutions in the kit (Nanjing Jiancheng Bioeng. Inst., Nanjing, China) in two steps to develop colour, a Spectromax microplate reader (M5, Molecular Devices, Sunnyvale, CA) can detect the absorbance and therefore calculate the plasma content of CHO, TG, HDL-C and LDL-C based on the standard curve.

Egg quality

Eight eggs/week were collected at random from each replicate during the last 4 weeks and these 32 eggs (192 eggs/treatment) were used for egg quality assessment. Eggshell thickness, egg length, and egg width were determined using a digital micrometer. The egg shape index was calculated as (width/length) × 100. Eggshell breaking strength was measured on the vertical axis using an Egg Force Reader (model EFR-01, ORKA Food Technology, Ramat HaSharon, Israel) (Chen et al. 2017). Albumen height, yolk colour, and Haugh unit of each egg were measured on the day of collection using an Egg Analyser (model EA-01, ORKA). The yolk was separated from albumen and weighed, and the yolk proportion (%) was calculated as (yolk weight/egg weight) × 100. One gram of yolk was quantitatively diluted to 100 mL with physiological saline (0.9% NaCl) and then 1 mL was used to measure yolk cholesterol (CHO) and triglycerides (TG) with commercial kits (purchased from Nanjing Jiancheng Bioeng. Inst., China) by detecting the colour of the quinone compound with the Spectromax microplate reader (M5, Molecular Devices, Sunnyvale, CA).

Fatty acid composition and linoleic acid content of feed

Yolk fatty acid profile was determined by gas chromatography of methyl esters in 8 eggs per replicate (n = 48 eggs/treatment). Lipids were extracted using chloroform: methanol solution (2:1 volume/volume, Folch et al. 1957) and fatty acid methyl esters (FAME) were obtained by reaction with 4% HCl in methanol for 20 min at 60 °C. The FAME were analysed by gas chromatography; a Hewlett-Packard 5890 series II gas chromatograph fitted with a flame-ionisation detector, 3396 A integrator and a Supelcovax-10 fused silica capillary column (60 m × 0.32 mm i.d., 0.25 μm film thickness, Sigma-Aldrich, St. Louis, MO) was used (Aydin and Cook 2004). The oven temperature was programmed to rise from 50 °C to 200 °C (20 °C/min), held for 50 min at 200 °C, then increased to 230 °C (10 °C/min), and held for an additional 20 min. Heptadecanoic acid (Sigma, Guangzhou, Guangdong) was used as an internal standard. The FAME was identified by comparison of their retention times with those of methylated fatty acid standards (Nu-Chek Prep, Elysian, MN) and expressed as a percentage of total FAME (Chin et al. 1992). Dietary linoleic acid from six treatments was assayed with the same methodology after lipid extraction.

Statistical analysis

Replicate ($n = 6$) was considered the experimental unit. Two birds per replicate were used for plasma analyses and 8 eggs for egg quality and yolk fatty acid profile assessment. The effects of linoleic acid were analysed by the one-way ANOVA procedure of SAS version 9.1 (Copyright (c) 2002/2012, SAS Inst. Inc., Cary, NC, USA) with $p < .05$ to indicate significance. Where appropriate, the linear and quadratic effects of the increasing levels of linoleic acid were estimated. Data for each variable are presented as means, with the SE for $n = 6$, derived from the ANOVA error mean square.

Results

Productive performance

There was no effect of increasing dietary LA from 0.36 to 1.45%, on the measured indices of productive performance over the whole 20 week period (Table 2). There was no mortality during the experiment. The average daily intake of dietary LA was 0.60, 1.10, 1.34, 1.79, 2.14 and 2.42 g, in the dietary treatments 0.36, 0.66, 0.80, 1.07, 1.28 and 1.45%, respectively.

Table 3. Effect of different concentrations of dietary linoleic acid on plasma lipid variables in laying ducks aged 44 weeks.

	Linoleic acid, %							
Variables	0.36	0.66	0.80	1.07	1.28	1.45	SEM	*p*-Value
Triglycerides, mmol/L	5.26	5.54	5.93	5.57	4.71	4.50	1.41	.91
Cholesterol, mmol/L	3.88	3.88	4.40	3.82	4.51	3.83	0.40	.31
LDL-C, mmol/L	2.34	2.50	2.88	2.30	2.79	2.34	0.30	.24
HDL-C, mmol/L	0.65	0.55	0.60	0.60	0.79	0.64	0.14	.63

Abbreviations. LDL-C: low-density lipoprotein cholesterol; HDL-C: high-density lipoprotein cholesterol.

Plasma analyses

Linoleic acid dietary supplementation did not significantly affect plasma concentrations of the lipid-related indicators: TG, CHO, LDL-C or HDL-C (Table 3).

Egg quality

As shown in Table 4, linoleic acid did not affect egg shape index, breaking strength, eggshell thickness, or Haugh unit. There was an effect of dietary LA content on yolk colour, primarily linear ($p < .001$) with a marginal quadratic component ($p = .029$) as the maximal colour occurred at 1.07 and 1.28%. There were no differences in yolk weight or proportion. Yolk cholesterol increased linearly ($p = .002$) with increasing dietary inclusion of LA. There were no effects of treatment on the content of yolk TG and albumin height.

Yolk fatty acid profiles

As shown in Table 5, increasing dietary LA did not affect the total proportion of saturated fatty acids (SFA). The proportions of C18:1(cis-9), C20:1, and total monounsaturated fatty acids (MUFA) were linearly decreased ($p < .001$ to .005) as a response to the increased dietary LA levels. Increasing dietary LA linearly increased proportions of C18:2, C18:3, C20:2 (all $p < .001$), C20:3 ($p < .003$), C20:4 ($p < .008$), C22:6 and total polyunsaturated fatty acids (PUFA) (both $p < .0001$); the proportion of PUFA was approximately doubled at the highest level of supplementation.

Discussion

Egg production and plasma lipid-related indicators

The present study demonstrated that LA dietary supplementation did not display any positive effect on most productive traits; though, egg production, egg yield, and FCR appeared to be slightly better with 0.66% LA level. There is scarce data on the available literature in support of this observation, and none refers to ducks. In laying hens, Liu et al. (2016) found a non-significant increase in egg production with 0.4, 0.8 and 1.6 LA than the controls (0% LA), and a significant decrease in feed conversion ratio with 1.6% LA; the same result was reported by Jung et al. (2011). These previous authors suggested that the improved FCR is associated with increased energy or antioxidant amount in the diets. The dietary antioxidants could improve the FCR by increasing nutrient utilisation through increased protection against oxidation and environmental stress (Sahin et al. 2005; Frikha et al. 2009). In brown laying hens, Safaa et al. (2008) reported that increasing dietary LA level from 1.12 to 1.60 did not affect the egg production or FCR. Grobas, Mendez, et al. (1999) observed a non-significant increase in some of the studied variables (egg production rate, egg weight, egg mass output) when LA content increased from 1.15 to 1.65%. In contrast, there are some reports indicating a significant effect of LA on productive performance. Menge (1970) reported that the optimal level of dietary LE for maximal egg production in laying hens is 2%, whereas using 0.75% or higher is adequate for maximal hatchability. Shutze and Jensen (1963) found that methyl LA and a 95%-purified LA supplement also significantly improved egg weight when added on an equivalent LA basis to 5% corn oil. In another study, Grobas, Mateos, et al. (1999) reported that egg weight significantly increased when dietary LA was raised from 0.79 to 2.73%, and recommended that not less than 1.03% LA is required for optimum egg weight. Scragg et al. (1987) reported that 2–4% LA resulted in the best egg weight. None of previous referred to LA requirement for laying ducks. In the present study with ducks, the dietary content of LA, between 0.36 and 1.45%, had no effect on egg weight and laying performance; the reason for the difference remains unclear.

In the ducks of the present study, LA did not affect the examined plasma lipid-related indicators. Earlier studies in a variety of species indicated that, as a member of the ω-6 PUFA, LA played a positive role in lipid metabolism by decreasing blood TG, CHO, LDL-C and increasing HDL-C (Deng 2005). Most of the previous research has been implemented in mice fed high-fat diets or used animal models with high cholesterol levels. The present evaluation of LA in normally-fed ducks

Table 4. Effect of different concentrations of dietary linoleic acid on duck egg quality.

	Linoleic acid, %							*p*-Value[a]		
Variables	0.36	0.66	0.80	1.07	1.28	1.45	SEM	linoleic acid	Linear	Quadratic
Shape index	73.55	72.73	72.85	72.05	71.52	71.76	0.29	.40		
Breaking strength, kgf	3.54	3.67	3.54	3.22	3.45	3.77	0.21	.59		
Shell thickness, mm	0.32	0.32	0.33	0.33	0.32	0.32	0.00	.71		
Albumen height, mm	5.91	5.76	6.20	5.75	6.13	6.17	0.21	.45		
Haugh unit	74.36	73.48	76.77	73.52	76.57	76.62	1.69	.49		
Yolk colour	2.22	2.28	2.61	3.11	3.00	2.72	0.19	<.01	.0007	.0290
Yolk Weight, g	20.59	20.70	20.35	20.11	20.52	20.17	0.44	.93		
Yolk proportion, %	33.10	33.20	31.30	32.20	33.40	32.20	1.01	.65		
Yolk cholesterol, mg/g	25.06	27.27	28.88	29.64	28.63	31.61	1.34	<.05	.0023	.5774
Yolk triglycerides, mg/g	264.10	271.78	270.74	279.94	280.34	286.55	11.75	.74		

[a]Linear and quadratic are only shown when main effect of linoleic acid was significant in ANOVA.

Table 5. Effect of different concentrations of linoleic acid on yolk fatty acid composition in yolk of laying ducks.

	Linoleic acid (%)							*p*-Value[a]		
Variables	0.36	0.66	0.80	1.07	1.28	1.45	SEM	linoleic acid	Linear	Quadratic
C14:0	0.38	0.34	0.37	0.34	0.32	0.35	0.02	.86		
C16:0	25.20	24.73	24.99	25.04	24.48	24.84	0.40	.23		
C17:0	0.11	0.12	0.12	0.14	0.14	0.14	0.01	<.01	<.0001	.8301
C18:0	6.01	5.49	5.99	5.99	5.96	6.20	0.25	.48		
SFA	31.69	30.67	31.48	31.51	30.89	31.54	0.53	.70		
C16:1(cis-9)	2.83	2.64	2.64	2.51	2.50	2.49	0.13	.47		
C18:1(cis-9)	55.43	57.20	54.66	52.21	53.28	52.14	0.86	<.01	<.0001	.9901
C20:1	0.39	0.39	0.37	0.36	0.37	0.31	0.02	<.05	.0038	.4151
MUFA	58.65	60.23	57.66	55.07	56.14	54.94	0.89	<.01	<.0001	.9335
C18:2	5.29	5.37	6.82	8.42	8.06	8.75	0.50	<.01	<.0001	.3229
C18:3	0.27	0.29	0.45	0.64	0.60	0.68	0.04	<.01	<.0001	.1669
C20:2	0.13	0.12	0.15	0.20	0.20	0.20	0.01	<.01	<.0001	.3909
C20:3	0.14	0.13	0.16	0.19	0.16	0.21	0.01	<.05	.0015	.7671
C20:4	0.91	0.87	0.91	1.05	0.95	1.11	0.05	<.05	.0076	.3440
C22:6	0.13	0.13	0.17	0.26	0.28	0.30	0.02	<.01	<.0001	.8550
PUFA	6.87	6.91	8.64	10.77	10.25	11.24	0.57	<.01	<.0001	.4083
UFA	65.52	67.13	66.30	65.84	66.38	66.18	0.49	.30		

[a]Linear and quadratic are only shown when main effect of linoleic acid was significant in ANOVA.
Abbreviations. SFA: saturated fatty acids; MUFA: total monounsaturated fatty acids; PUFA: total polyunsaturated fatty acids; UFA: unsaturated fatty acids.

clearly showed that the levels 0.36–1.45% did not cause any significant effect on plasma lipid variables.

Egg quality and yolk fatty acid profiles

Linoleic acid affected the yolk colour and the CHO content of the yolk, but not the other indices of egg quality. In the majority of the studies with hens, researchers reached to the same conclusions. For example, Shutze and Jensen (1963), Grobas, Mateos, et al. (1999), and Whitehead (1984) found that dietary LA content showed a little effect on the weights of yolk, albumen, other egg components, and shell plus membranes throughout the laying cycle. Similarly, Safaa et al. (2008) found that reducing the LA content of the diet from 1.60 to 1.12% did not modify any egg quality trait at any age. In contrast to the present findings, March and Macmillan (1990) found that when diets deficient in essential fatty acids are supplemented with LA, yolk weight increases, probably through an improvement in the mechanism by which lipoproteins are synthesised or taken up by the developing ova (Whitehead et al. 1993). Liu et al. (2016) found that the yolk colour of eggs from hens fed 1.6% of dietary LA was significantly deepened than those from hens fed 0, 0.4, and 0.8% dietary LA. The LA has a strong anti-oxidantive capacity which may help in preventing carotenoid oxidisation and therefore promotes its deposition in the egg yolk (Chamruspollert and Sell 1999; Liu et al. 2016) Yolk colour mostly depends on the dietary content of lutein, carotenoids and dietary fat levels. The present results showed that LA may improve yolk pigmentation by increasing the yolk fat, but this finding needs further clarification.

In tilapia, linear responses in whole body LA (R^2 = 0.641) and arachidonic acid (R^2 = 0.746) occurred with increasing dietary levels of LA (El–Husseiny et al. 2010). In mice, Weldon and Whelan (2011) found that at the same energy level, LA content of the diet significantly affected the LA proportion of mouse plasma and erythrocyte phospholipid, and reduced the 18:1n-9 proportion in erythrocyte phospholipid. Liu et al.

(2016) reported that that the total amounts of LA transferred into egg yolk lipids correlated significantly and positively with dietary LA; LA supplementation led to significantly higher polyunsaturated fatty acid (PUFA) contents compared with the controls, and significantly lower monounsaturated fatty acids (MUFAs). These outcomes were similar to that of the present study with laying ducks. In the present study, dietary LA significantly affected the egg yolk fatty acid composition of ducks. As a constituent of PUFA, the proportion of LA itself in the yolk was significantly increased with a greater dietary provision, along with the other PUFA (including n-3 fatty acids). This may be related to changes in the overall fatty acid composition of the diet resulting from increased content of soybean oil, relative to sodium palmate, with increased content of LA (C18:2n-6), alpha-linolenic acid (C18:3n-3) and the former two can be used to synthesise ω-6 and ω-3 fatty acids in animals. Arachidonic acid (**AA**, C20:4n-6) and docosahexaenoic acid (DHA, C22:6n-3) are the members of ω-6 and ω-3 fatty acids with particularly important biological functions and significance. Our results indicated that the dietary LA showed a physiological role in modifying the proportions of egg yolk FA profile, which were supported by those of Ahn et al. (1999), Raes et al. (2002), and Liu et al. (2016). Liu et al. (2016) suggested that the dietary LA increased the PUFA in egg yolk through inhibiting the enzyme delta-6-desaturase; a key enzyme that converts linolenic acid into fatty acids of C20:5 series. Belury and Kempa-Steczko (1997) reported that dietary LA is an inhibitor of the enzyme delta-6-desaturase. In the case of inhibiting the delta-6 desaturase enzyme, hens become unable to convert C18:3 FAs to C20:5 FAs, resulting in increased PUFAs content in egg yolk (Liu et al. 2016). Additionally, the dietary LA was suggested to modify the egg yolk content of SFAs and MUFAs through inhibiting the enzyme delta-9-desaturase, a key enzyme that converts SFAs to the corresponding MUFA, leading to increased SFAs and decreased MUFAs (Liu et al. 2016). In a nutritional context, therefore, the increased yolk content of PUFA in laying ducks, achieved here by increasing dietary beneficial fatty acids, has important practical significance.

Conclusions

The results of the present study revealed that increasing dietary LA (0.36–1.45% of the diet) in laying ducks was shown to increase the yolk content of DHA, AA, and related PUFA along with yolk colour. Based on the variables considered here, a case can be made for modest increases in dietary LA for laying ducks to achieve a higher value consumer product with an enhanced content of PUFA.

Ethical approval

This study was approved by the Animal Care and Use Committee of Guangdong Academy of Agriculture Science, with the approval number (GAASIAS-2016-017).

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Disclosure statement

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