Article

Effect of Dietary Vitamin E on Growth Performance, Immunity and Antioxidant Capacity in Male Jiangnan White Goslings from 1 to 28 d of Age

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Abstract: This experiment aimed to investigate effects of the different dietary levels of vitamin E (VE) on the growth performance, immunity and antioxidant capacity of goslings. A total of 240 1-day-old, male Jiangnan white goslings were selected and randomly divided into 6 groups. Each treatment included five replicates. The basal diet was supplemented with 6 concentrations of VE (0, 12, 24, 36, 48 and 60 mg DL- α -tocopherol acetate/kg). The results were as follows: (1) The α -tocopherol content in the serum and liver of goslings increased linearly as supplemental VE increased in diet ($p < 0.05$). (2) The body weight (BW) and average daily gain (ADG) increased quadratically with increasing dietary VE supplementation ($p < 0.05$). Dietary VE supplementation could significantly reduce the feed/gain ratio (F/G) ($p < 0.05$). (3) Dietary supplementation with VE could significantly improve the contents of immunoglobulin A (IgA) and immunoglobulin G (IgG) in the serum of the goslings ($p < 0.05$). The content of interferon- γ (IFN- γ) in the serum was significantly reduced with VE supplementation ($p < 0.05$). (4) Dietary supplementation with VE could significantly improve serum and liver catalase (CAT), superoxide dismutase (SOD) activities and liver total antioxidant capacity (T-AOC) ($p < 0.05$); Serum and liver MDA contents were significantly reduced with VE supplementation ($p < 0.05$). In summary, dietary supplementation with VE could improve growth performance, immunity and antioxidant capacity. Based on broken-line regression analysis, the dietary VE supplementation level for ADG was 12.51 mg/kg, but higher supplementation level should be considered to improve immunity and antioxidant capacity.

Keywords: gosling; vitamin E; growth performance; immunity; antioxidant capacity

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1. Introduction

Vitamin E (VE), divided into tocopherols and tocotrienols, is one of the essential fat-soluble vitamins for animals. Animals that cannot synthesize VE must obtain it from the diet [1]. α -Tocopherol has high biological activity and is the main storage form of VE in animal tissues accounting for more than 90% of VE [2]. The content of α -tocopherol in the blood and liver were shown to depend on the dietary VE levels added to feed [3].

VE could improve immunity and antioxidant capacity [4] and was shown to play a very important role in poultry production. The average daily gain (ADG) of broilers in the 100 mg/kg VE group was significantly higher than that in the control group supplemented with 18.75 mg/kg VE [5]. Chae et al. [6] reported that adding 10–200 mg/kg α -tocopherol acetate to broiler diets could significantly improve growth performance compared with that of the control group with no supplementation. Adding 5–100 mg/kg α -tocopherol acetate to starter White Pekin duck diet was shown to significantly improve growth performance compared with that of the control group with no supplementation [7]. VE is an important

regulatory factor in the immune response that can enhance humoral and cellular immune responses. The levels of interferon- γ (IFN- γ) in the plasma and tissues of broiler chicks were shown to be lower in the 50 mg/kg RRR- α -tocopherol succinate group than that in the 10 mg/kg RRR- α -tocopherol succinate group [8]. Adding 220 mg/kg α -tocopherol acetate to broiler diets was shown to relieve inflammation [9]. As the main antioxidant of the cell membrane, VE is a chain-breaking antioxidant, that can prevent the formation of free radicals in cell membrane [10,11]. When animals lack VE, the content of α -tocopherol in tissues decreases and the degree of lipid peroxidation increases [12].

At present, some studies have shown that appropriate VE supplementation in diet can improve the growth performance, immunity, and antioxidant capacity of poultry. Although there were studies on VE in goslings [13,14], there have been few studies to determine appropriate VE supplementation in the diet of goslings. Therefore, the objective of this study was to investigate the effects of different supplemental doses of VE on growth performance, immunity and antioxidant capacity as a reference for the production of goslings.

2. Materials and Methods

2.1. Experimental Design and Diets

The Yangzhou University (Yangzhou, China) Animal Care and Use Committee approved all procedures in our experiments, with permit number: SYXK (Su) IACUC 2012-0029.

A total of 240 1-day-old, male Jiangnan white goslings were selected and randomly divided into 6 experimental groups. Each treatment included five replicates. The basal diet was supplemented with 6 concentrations of VE (0, 12, 24, 36, 48 and 60 mg/kg). The form of VE added to the feed was DL- α -tocopherol acetate. DL- α -tocopherol acetate was purchased from Yangzhou Shuangyang Biological Co., Ltd. (Yangzhou, China). A basal maize-soybean meal diet was formulated to provide an adequate concentration of all the nutrients, except for VE, required by goslings NRC [15] and optimized in our laboratory over the years (Table 1). All goslings had free access to feed and water. The goslings were maintained under natural daylight and ventilation and kept at a temperature of 28 ± 3 °C. The size of each pen was 2.52 m² (2.10 m $\times$ 1.20 m).

2.2. Sample Collection and Index Determination

2.2.1. α -Tocopherol Content

The content of α -tocopherol in feed, serum and liver was determined using reversed phase high performance liquid chromatography (2695 Alliance, Waters, Milford, MA, USA) with fluorescence detection according to the method of Jensen et al. [16].

2.2.2. Growth Performance

On day 28, goslings were weighed after a 6-h fast and feed intake was recorded in replicates to calculate average daily gain (ADG) and average daily feed intake (ADFI). The feed/gain ratio (F/G) was calculated as the ratio between the ADFI and ADG of each replicate. The body weight (BW) and feed intake were recorded by an electronic platform scale (acs-30 Shanghai Yousheng Co., Ltd., Shanghai, China).

2.2.3. Immunity

The contents of serum immunoglobulin M (IgM), immunoglobulin A (IgA), immunoglobulin G (IgG), interleukin-6 (IL-6) and interferon- γ (IFN- γ) were measured by double antibody sandwich enzyme-linked immunosorbent assay (ELISA) using commercial kits from Shanghai Yubo Biology Co., Ltd. (Shanghai, China).

Table 1. Composition and nutrient level of the basic gosling diet (dry basis).

Item	Content
Ingredients (%)	
Corn	59.50
Soybean meal	31.10
Rice husk	2.90
Wheat bran	2.96
Methionine	0.14
Salt	0.30
Stone powder	0.75
Calcium hydrogen phosphate	1.25
Choline chloride	0.10
Premix ¹	1.00
Total	100.00
Nutritional level ²	
ME (MJ/kg)	11.40
Crude protein (%)	19.30
Crude fiber (%)	4.89
Ca (%)	0.80
Available phosphorus (%)	0.42
Lysine (%)	0.97
Methionine (%)	0.42
α -tocopherol (mg/kg) ²	15.45

¹ Each kilogram of premix contains: VA 900,000 IU, VD₃ 300,000 IU, VK 225 mg, VB₁ 90 mg, VB₂ 800 mg, VB₆ 320 mg, VB₁₂ 1 mg, Nicotinic acid 4500 mg, pantothenic acid 1100 mg, folic acid 65 mg, biotin 5 mg, Fe (ferrous sulfate) 6 g, Cu (copper sulfate) 1 g, Mn (manganese sulfate) 9.5 g, Zn (zinc sulfate) 9 g, Se (sodium selenite) 30 mg, I (potassium iodide) 50 mg; ² The content of α -tocopherol was measured value and the rest were calculated.

2.2.4. Antioxidant Capacity

Each liver sample was accurately weighed to 0.5 g, and a 9-fold volume of physiological saline by weight was added. The sample was homogenized under ice bath conditions by a variety of fast homogenizers. By using a DL-5 M low-speed refrigerated centrifuge at 2500 r/min, the liver samples were centrifuged for 10 min, one portion was retained for inspection, and the others were stored at -70°C for later testing. The DL5 M low-speed refrigerated centrifuge was purchased from Hunan Xiangyi Centrifuge Instrument Co., Ltd., (Hunan, China). The catalase (CAT), glutathione peroxidase (GSH-Px) and superoxide dismutase (SOD) activities; total antioxidant capacity (T-AOC); and malondialdehyde (MDA) content in serum and liver were determined by using an assay kit purchased from Nanjing Jiancheng Bioengineering Research Institute (Nanjing, China) and following the operation manual.

2.3. Statistical Analysis

Data were analyzed using SPSS 17.0 (SPSS, 2009) by univariate variance analysis (ANOVA) following Tukey test to elucidate significant differences at $p < 0.05$. VE supplementation level was estimated from the ADG using broken-line regression model analysis [17]. If the value of R^2 was less than 0.50, we would not use broken-line regression model to analyze the data.

3. Results

3.1. Serum and Liver α -Tocopherol Content

The content of α -tocopherol in the liver and serum increased linearly with increasing dietary VE supplementation ($p < 0.05$) (Table 2).

Table 2. Effect of dietary vitamin E supplementation on α -tocopherol content in the serum and liver of male Jiangnan white goslings on day 28.

Item	Vitamin E Supplementation Level (mg/kg)						SEM	p-Value		
	0 ¹	12	24	36	48	60		Vitamin E	Linear	Quadratic
Serum (ug/mL)	1.20 ^d	2.76 ^c	3.87 ^{b,c}	4.65 ^b	6.93 ^a	7.96 ^a	0.44	<0.001	<0.001	0.338
Liver (ug/g)	1.43 ^d	1.91 ^d	3.07 ^c	3.55 ^{b,c}	3.99 ^b	4.59 ^a	0.21	0.001	<0.001	0.075

¹ The content of α -tocopherol in the basal diet was 15.45 mg/kg; ^{a–d} Means with different superscripts within the same column differ significantly ($p < 0.05$).

3.2. Growth Performance

The effect of dietary VE supplementation on the growth performance of goslings on day 28 is shown in Table 3. The BW and ADG of gosling in groups with 12, 36, 48 and 60 mg/kg supplementation were higher than those of the group with 0 mg/kg supplementation ($p < 0.05$). Dietary VE supplementation had no significant effects on ADFI ($p > 0.05$). The F/G of goslings in groups with 36 and 48 mg/kg supplementation was less than that of the group with 0 mg/kg supplementation ($p < 0.05$). The optimal VE supplementation level for male Jiangnan white goslings from 1 to 28 d of age was 12.51 mg/kg for maximum ADG (Table 4).

Table 3. Effect of dietary vitamin E supplementation on the growth performance of male Jiangnan white goslings from hatching to 28 d.

Item ¹	Vitamin E Supplementation Level (mg/kg)						SEM	p-Value		
	0 ²	12	24	36	48	60		Vitamin E	Linear	Quadratic
Hatch weight (g)	94.3	94.8	94.4	94.3	94.6	94.5	0.09	0.519	0.688	0.950
28 d BW (g)	1586.8 ^b	1679.0 ^a	1659.2 ^{a,b}	1716.4 ^a	1676.2 ^a	1684.0 ^a	10.67	0.005	0.005	0.013
ADG (g)	53.3 ^b	56.6 ^a	55.9 ^{a,b}	57.9 ^a	56.5 ^a	56.8 ^a	0.38	0.005	0.005	0.013
ADFI (g)	116.8	119.3	117.1	119.0	116.9	118.9	0.70	0.831	0.748	0.903
F/G (g/g)	2.19 ^a	2.11 ^{a,b}	2.10 ^{a,b}	2.06 ^b	2.07 ^b	2.10 ^{a,b}	0.01	0.014	0.005	0.010

¹ BW = body weight; ADG = average daily gain; ADFI = average daily feed intake; F/G = The feed/gain ratio;

² The content of α -tocopherol in the basal diet was 15.45 mg/kg; ^{a,b} Means with different superscripts within the same column differ significantly ($p < 0.05$).

Table 4. Vitamin E supplementations of male Jiangnan white goslings from 1 to 28 d of age based on broken-line regression analysis.

Response Criterion ¹	Regression	Supplementation (mg/kg)	p-Value	R ²
ADG	$Y = 57.2175 - 0.3544(12.51 - x)$	12.51	0.0002	0.56
Serum INF- γ content	$Y = 41.1400 + 0.4100(38.12 - x)$	38.12	<0.0001	0.61
Liver MDA content	$Y = 0.4601 + 0.0072(25.94 - x)$	25.94	<0.0001	0.50

¹ ADG = average daily gain; IFN- γ = interferon- γ ; MDA = malondialdehyde.

3.3. Immunity

The effect of dietary VE supplementation on the immunity of goslings on day 28 is presented in Table 5. The content of IgA in the serum of goslings in the 36 and 48 mg/kg groups was higher than that in the 0 mg/kg group ($p < 0.05$). The content of IgM in the serum of goslings in all groups had no differences ($p > 0.05$). The IgG content in the serum of the goslings in the 48 mg/kg group was higher than that in the 0 mg/kg group ($p < 0.05$). Dietary VE supplementation showed no significant effects on the content of IL-6 in serum ($p > 0.05$). The content of IFN- γ in serum 48 mg/kg was less than that of 0 mg/kg group ($p < 0.05$). Table 4 shows that the VE supplementation for male Jiangnan white goslings from 1 to 28 days of age was 38.121 mg/kg of the diet for minimum content of IFN- γ .

Table 5. Effect of dietary dietary vitamin E supplementation on immunity in the serum of male Jiangnan white goslings on day 28.

Item ¹	Vitamin E Supplementation Level (mg/kg)						SEM	<i>p</i> -Value		
	0 ²	12	24	36	48	60		Vitamin E	Linear	Quadratic
IgA (mg/mL)	0.14 ^b	0.16 ^{a,b}	0.16 ^{a,b}	0.22 ^a	0.22 ^a	0.19 ^{a,b}	0.01	0.005	0.002	0.066
IgM (mg/mL)	1.81	1.82	1.96	2.18	2.07	1.95	0.04	0.069	0.039	0.067
IgG (mg/mL)	1.63 ^b	1.70 ^{a,b}	1.70 ^{a,b}	1.87 ^{a,b}	2.09 ^a	1.82 ^{a,b}	0.05	0.028	0.008	0.349
IL-6 (ng/L)	24.81	24.34	21.16	21.42	21.85	23.08	0.70	0.574	0.290	0.167
IFN- γ (ng/L)	57.79 ^a	51.52 ^{a,b}	45.34 ^{a,b}	43.27 ^{a,b}	39.23 ^b	43.04 ^{a,b}	1.43	<0.001	<0.001	<0.001

¹ IgM = immunoglobulin M; IgA = immunoglobulin A; IgG = immunoglobulin G; IL-6 = Interleukin-6; IFN- γ = interferon- γ ; ² The content of α -tocopherol in the basal diet was 15.45 mg/kg; ^{a,b} Means with different superscripts within the same column differ significantly ($p < 0.05$).

3.4. Antioxidant Capacity

Table 6 shows that the effect of dietary VE supplementation on the serum antioxidant capacity of goslings on day 28. The serum CAT activity of goslings in groups with 24, 36 and 48 mg/kg supplementation was higher than that of group 0 mg/kg ($p < 0.05$). Dietary VE supplementation had no effects on GSH-Px activity and T-AOC ($p > 0.05$). The SOD activity of goslings in group with 36 mg/kg supplementation was higher than that of group 0 mg/kg ($p < 0.05$). The serum MDA content in groups 24, 36, 48 and 60 mg/kg significant less than that of group 0 mg/kg ($p < 0.05$).

Table 6. Effect of dietary vitamin E supplementation on the antioxidant capacity in the serum of male Jiangnan white goslings on day 28.

Item ¹	Vitamin E Supplementation Level (mg/kg)						SEM	<i>p</i> -Value		
	0 ²	12	24	36	48	60		Vitamin E	Linear	Quadratic
CAT (U/mL)	2.44 ^b	2.80 ^{a,b}	2.97 ^a	2.92 ^a	2.87 ^a	2.82 ^{a,b}	0.05	0.012	0.017	0.003
GSH-Px (U/mL)	200.73	210.27	213.00	229.36	218.18	219.27	3.00	0.110	0.027	0.127
T-AOC (U/mL)	12.95	13.78	12.89	13.25	13.99	14.27	0.25	0.510	0.152	0.510
SOD (U/mL)	161.01 ^b	170.73 ^{a,b}	173.16 ^{a,b}	175.59 ^a	173.47 ^{a,b}	170.43 ^{a,b}	1.46	0.048	0.038	0.009
MDA (nmol/mL)	7.02 ^a	6.04 ^{a,b}	5.64 ^b	5.42 ^b	5.70 ^b	5.32 ^b	0.14	0.001	<0.001	0.023

¹ CAT = catalase; GSH-Px = glutathione peroxidase; T-AOC = total antioxidant capacity; SOD = superoxide dismutase; MDA = malondialdehyde; ² The content of α -tocopherol in the basal diet was 15.45 mg/kg; ^{a,b} Means with different superscripts within the same column differ significantly ($p < 0.05$).

The effect of dietary VE supplementation on the liver antioxidant capacity of goslings on day 28 is presented in Table 7. The activity of CAT in the liver of goslings in the 36 mg/kg group was higher than that in the 0 mg/kg groups ($p < 0.05$). The activity of GSH-Px in the liver of goslings in all groups had no significant differences ($p > 0.05$). The liver T-AOC in groups 12, 24, 36, 48 and 60 mg/kg was higher than that in group 0 mg/kg ($p < 0.05$). The activity of SOD in the liver of goslings in the 60 mg/kg group was higher than that in the 0 groups ($p < 0.05$). The liver MDA content of goslings in the 24, 36 48 and 60 mg/kg groups was less than that of the 0 mg/kg group ($p < 0.05$). The VE supplementation for male Jiangnan white goslings from 1 to 28 days of age was 25.94 mg/kg of the diet for minimum content of MDA in liver (Table 4).

Table 7. Effect of dietary vitamin E supplementation on the antioxidant capacity in the liver of male Jiangnan white goslings on day 28.

Item ¹	Vitamin E Supplementation Level (mg/kg)						SEM	<i>p</i> -Value		
	0 ²	12	24	36	48	60		Vitamin E	Linear	Quadratic
CAT (U/mg prot)	38.65 ^b	42.67 ^{a,b}	46.41 ^{a,b}	52.60 ^a	48.01 ^{a,b}	47.70 ^{a,b}	1.21	0.009	0.003	0.020
GSH-Px (U/mg prot)	18.05	20.06	20.01	20.59	21.61	20.79	0.50	0.481	0.082	0.394
T-AOC (U/mg prot)	8.10 ^b	10.49 ^a	10.83 ^a	10.04 ^a	10.34 ^a	10.31 ^a	0.25	0.016	0.034	0.017
SOD (U/mg prot)	134.92 ^b	145.38 ^{a,b}	154.87 ^{a,b}	164.92 ^{a,b}	164.17 ^{a,b}	172.78 ^a	3.61	0.013	<0.001	0.461
MDA (nmol/mg prot)	0.66 ^a	0.53 ^{a,b}	0.49 ^b	0.41 ^b	0.46 ^b	0.51 ^b	0.02	<0.001	0.001	<0.001

¹ CAT = catalase; GSH-Px = glutathione peroxidase; T-AOC = total antioxidant capacity; SOD = superoxide dismutase; MDA = malondialdehyde; ² The content of α -tocopherol in the basal diet was 15.45 mg/kg; ^{a,b} Means with different superscripts within the same column differ significantly ($p < 0.05$).

4. Discussion

4.1. Serum and Liver α -Tocopherol Content

Fat-soluble vitamins can be absorbed into the poultry body with lipids and stored in body in the other forms. α -Tocopherol binds to various lipoproteins in the Golgi apparatus of epithelial cells to form chyme and then enters the lymphatic circulation. High-density lipoprotein (HDL) synthesized by intestinal cells could also carry α -tocopherol into the blood circulation [18,19]. α -Tocopherol was shown to be absorbed into the blood and entered the liver via the hepatic portal vein. Moreover, the liver tissue was shown to be the main organ of α -tocopherol deposition [20]. The liver plays an important role in the storage, regulation and metabolism of α -tocopherol [21]. Dynamic balance and regulatory mechanisms exist for α -tocopherol levels in the blood and liver. α -Tocopherol transfer protein (α -TTP) can transfer α -tocopherol from the liver to the blood, effectively retaining α -tocopherol in the body and significantly increasing the content of α -tocopherol in serum [22]. Zhang et al. [23] showed that increasing the content of dietary VE could significantly increase the content of α -tocopherol in plasma and liver of broilers. Russell et al. [24] showed that the levels of α -tocopherol in the serum and liver of ducks in the group supplemented with 400 mg/kg α -tocopherol acetate were significantly higher than those in the control group supplemented with 20 mg/kg α -tocopherol. Our results showed that with increasing dietary VE supplementation, the content of α -tocopherol in the serum and liver increased linearly.

4.2. Growth Performance

Adding the appropriate amount of VE to the diet can improve production performance of poultry. VE could regulate body metabolism through signal transduction to improve production performance [25,26]. Siegel et al. [27] and Boa-Amponsem et al. [28] observed that dietary VE supplementation could significantly increase the BW of broilers. Rebole et al. [29] reported that the BW and feed conversion ratio of female chickens in the group supplemented with 200 mg/kg α -tocopherol acetate were significantly higher than those in the non-supplemental group. Xie et al. [7] showed that the ADG of Peking ducks in groups supplemented with 10 mg/kg, 20 mg/kg and 100 mg/kg α -tocopherol acetate was significantly higher than that in the group supplemented with 0 mg/kg α -tocopherol acetate, and there were no differences in the ADG among the groups with 10 mg/kg, 20 mg/kg and 100 mg/kg α -tocopherol acetate supplementation. In our study, dietary VE supplementation could increase the BW, ADG and reduce the F/G of goslings. Our results were consistent with those of previous studies. Our results were consistent with those of previous studies. These results showed that VE supplementation did not promote growth performance when the amount of VE added to the feed met the growth requirements. Another study observed that high doses of VE could reduce the production performance of poultry. When the dietary VE supplementation levels were 0 and 250 mg/kg, the F/G of broilers was higher than the dietary VE supplementation level of 125 mg/kg [30]. In this experiment, based on broken-line regression analysis, the optimal VE supplementation

level for male Jiangnan white goslings from 1 to 28 d of age was 12.51 mg/kg for maximum ADG.

4.3. Immunity

VE plays an important role in poultry immunity. VE could regulate the levels of cytokines and immunoglobulin in serum to enhance the immune ability of animals [31]. Lin and Chang [32] observed that dietary supplementation with 20 mg/kg VE could significantly improve the immune response of chickens. Liu et al. [33] found that the content of IgA and IgG in laying hens in a group supplemented with 30 IU/kg VE was higher than that in a group supplemented with 0 IU/kg VE, but had no significant effects on the content of IL-6 in the serum. In our study, VE increased the content of IgA and IgG in serum of goslings on day 28, which was consistent with previous studies. Another study showed that the content of IFN- γ in the serum of laying hens in the group supplemented with 50 mg/kg RRR- α -tocopherol succinate was significantly lower than that in the group supplemented with 10 mg/kg RRR- α -tocopherol succinate [8]. In this experiment, we observed the same results. IFN- γ is a pro-inflammatory factor. The content of IFN- γ in serum was reduced which suggested that VE could improve the immune capacity and reduce the inflammatory response of goslings on day 28. Our research showed that VE could enhance the humoral immunity of goslings by increasing the content of serum immunoglobulin and reducing inflammation to maintain the health of goslings. Improving immunity is beneficial for keeping animals in a healthy state and promoting growth.

4.4. Serum and Liver Antioxidant Capacity

VE can improve the antioxidant capacity of poultry. When the body produces too many free radicals or endogenous antioxidant enzymes and exogenous antioxidants are reduced, the imbalance between the generation and elimination of free radicals causes oxidative stress [34]. As an exogenous nonenzymatic antioxidant, VE can react with excess free radicals in the body and prevent free radical chain reactions, which play an important role in preventing lipid peroxidation and improving the activity of antioxidant enzymes in animals [35,36]. Studies have reported that with increasing dietary VE supplementation levels, the activity of antioxidant enzymes in serum was significantly increased and the MDA content in serum was significantly decreased [37,38]. Asghar et al. [18] observed that thiobarbituric acid reactive substances (TBARS) in the liver and muscle decreased with increasing of VE supplementation. Goi et al. [39] reported that the MDA content in chicken muscle of test groups was significantly less than that in chicken muscle of the control group. The results of this experiment showed that dietary VE supplementation could significantly increase the activities of CAT and SOD in the serum and liver. The T-AOC was also significantly increased in the liver, and dietary VE supplementation significantly decreased the content of MDA in the serum and liver. The results were consistent with those of previous studies. In our study, the content of α -tocopherol in the serum and liver of goslings was increased, and α -tocopherol improved the activity of antioxidant enzymes. With increasing α -tocopherol content and antioxidant enzyme activity, the lipid peroxidation level has been shown to decrease [40,41]. Reducing lipid peroxidation could reduce the damage to cells and ensure the normal metabolism of cells [42]. In this experiment, adding appropriate VE to the diet improved the antioxidant capacity of goslings, reduced lipid peroxidation damage to organs and tissues, and improved immunity and growth performance.

5. Conclusions

In summary, adding an appropriate amount of VE to the diet can improve the growth performance, immunity and antioxidant capacity of male Jiangnan white goslings from 1 to 28 d of age. In this experiment, according to broken-line regression, the dietary VE supplementation level for average daily gain was 12.51 mg/kg, but higher supplementation level should be considered to improve immunity and antioxidant capacity.

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Conflicts of Interest: All the authors involved in this work declare that they have no conflict of interest.

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