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Effects of supra-nutritional levels of vitamin E and vitamin C on growth performance and egg production traits of Japanese quails

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ABSTRACT

A study was conducted to evaluate growth performance and egg production traits of Japanese quails fed diets containing different supra-nutritional levels of vitamin E and C (600, 800 and 1000 mg/kg). A completely randomised design was adopted and main effects (vitamin E and C) were arranged in a 3×3 factorial approach. Throughout the study (42 to 105 d), the highest feed intake (vitamin C, $p = .01$) and weight gain (vitamin E × C, tendency $p = .06$) were obtained with vitamin E and/or C at 800 mg/kg whereas the highest dietary efficiency with 600 mg/kg of vitamin E plus 600 or 1000 of C and with 800 mg/kg of E plus 600 or 800 mg/kg of C (vitamin E × C, tendency $p = .06$). The highest final body weight was achieved with 1000 mg/kg of both the vitamins (vitamin E × C, $p = .02$). Vitamin E and/or C at 1000 mg/kg increased egg production, weight of produced eggs (vitamin E × C, $p = .04$), number of produced eggs to feed ratio, weight of produced eggs to feed ratio (vitamin E and C, $p < .01$), average egg volume (vitamin E × C, $p = .03$), and egg shape index (vitamin E, $p < .01$; vitamin C, $p = .01$). Current findings showed that feeding vitamin E and C at supra-nutritional levels can be a good management practice in Japanese quail nutrition to promote growth performance and egg production traits under thermoneutral condition.

HIGHLIGHTS

- Supra-nutritional levels of vitamin E and C can promote growth performance and egg production traits of Japanese quails.
- Vitamin E plus C at high doses (1000 mg/kg) can synergistically act in promoting quail growth.
- Dietary supplementation with vitamin E at 800 or 1000 mg/kg plus vitamin C at 1000 mg/kg can improve egg production traits.

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Egg production traits; growth performance; Japanese quail; vitamin C; vitamin E

Introduction

The avian egg is an important source of nutrients containing all of the proteins, lipids, vitamins and minerals as well as growth and defence factors necessary for embryo development (Tolik et al. 2014). Moreover, eggs and egg components are of great importance for human health and in disease prevention and treatment thanks to their content in numerous substances with biological functions and activities (i.e. antioxidants, antimicrobials, immunomodulators, anticancer, etc.; Kovacs-Nolan et al. 2005). Although chicken eggs are most commonly eaten by humans, a lot of people, especially in Asian countries, consume quail eggs (Tunsaringkarn et al. 2013). Moreover, the consumption of quail eggs is becoming more popular also in Europe and America (Tolik et al. 2014) because quail eggs, despite their small size, have a nutritional value three or four times greater than chicken eggs (Tunsaringkarn et al. 2013). To meet the increasing demand for quail eggs as well as meat, the rearing of commercial quails, such as Japanese quail (*Coturnix coturnix Japonica*) selected for rapid growth and high body weight, has been raising worldwide (Hemid et al. 2010).

The birds' survival rate, egg-laying level and egg physical traits are the most crucial factors in quail production (Lukaszewicz et al. 2007; Lin et al. 2004). Natural antioxidants are important in promoting the health of birds with high level of egg laying (Lukaszewicz et al. 2007). Vitamin E and vitamin C play

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a major role as antioxidants in biological systems and act individually or synergistically such that vitamin E explicates its antioxidant function in lipid phases whereas vitamin C in aqueous compartments by reacting with peroxyl radicals and by restoring the antioxidant properties of vitamin E (Cotelle et al. 2003). Studies on poultry have reported that dietary supplementation with vitamins E and C, alone or together, can improve growth performance (Sahin and Kucuk 2001; Ajakaiye et al. 2010), egg production and egg quality (Ajakaiye et al. 2011; Caurez and Olo 2013). Because the most of studies were conducted under heat stress condition, further research is necessary to study the effects of additional vitamin E and C in diet of quails reared under standard environmental condition.

Therefore, the aim of this work was to evaluate the effects of different supra-nutritional levels of vitamins E and C on growth performance and egg production traits of Japanese quail during the laying period under thermoneutral environmental condition.

Materials and methods

Birds, housing and diets

All procedures were approved by the Animal Care and Welfare Committee of Islamic Azad University.

The current work was conducted at a quail farm (Amol, Iran) during March–May 2016 and represents the continuation of our previous study (Sigolo et al. 2018). At the end of the trial described by Sigolo et al. (2018), the same quails [a total of 360 Japanese female quails (*Coturnix coturnix Japonica*), 6 weeks old] were used in the current study. Housing and experimental design were as reported by Sigolo et al. (2018). Briefly, there were 9 dietary treatments and birds were subdivided into 4 replicates for each dietary treatment (10 birds/replicate) for a total of 36 experimental units. Each replicate was housed in a ground cage (0.70 m × 0.50 m).The trial was conducted under controlled environmental conditions. Temperature and relative humidity were respectively maintained at 24 °C and 55–65% and were near to those used by Minvielle et al. (1999) and Şahin et al. (2001). Throughout the experimental trial, the lighting programme consisted of 17 h of light and 7 h of dark in accordance with Şahin et al. (2001) and Sahin et al. (2002a).

Quail responses to different dietary levels of vitamin E and C were evaluated from 42 to 105 d of age. The standard diet was formulated to meet the nutritional requirements of breeding Japanese quails as recommended by NRC (1994). Ingredients, chemical composition and energy of the standard diet are shown in Table 1. The standard diet was supplemented with vitamin E (DL-α-tocopheryl acetate) and C (L-ascorbic acid) at 3 different levels (600, 800 and 1000 mg/kg of diet) in a 3 × 3 factorial design. All the experimental diets were iso-energetic and iso-nitrogenous. Water and experimental diets were offered *ad libitum*.

Table 1. Ingredients, chemical composition, and energy of the standard quail diet (from 42 to 105d of age).

	Diet from 42 to 105d
Ingredients, %	
Corn	50.00
Soybean meal, 44% protein	30.17
Wheat	4.42
Barley	2.96
Rapeseed oil	4.75
Salt	0.27
Mineral oysters	3.79
Bone meal	2.91
Vitamin and mineral premix[1]	0.50
DL-methionine	0.10
Lysine hydrochloride	0.08
Enzyme	0.05
Calculated analysis, % as fed	
ME, kcal/kg	3000.00
CP	20.00
Ca	2.50
Available P	0.55
Met	0.45
Met + Cys	0.76
Lys	1.15

[1]Supplied the following per kilogram of diet: Cu, 8 mg; Fe, 50 mg; Mn, 70 mg; Zn 50 mg; I, 1.2 mg; Se, 0.2 mg; vitamin A, 14000 U; vitamin D3, 4000 U; vitamin E, 10 mg; vitamin K3, 3.2 mg; vitamin B2, 6mg; vitamin B12, 16 μg; niacin, 40 mg; pantothenic acid, 10 mg; antioxidant, 30 mg.

Growth performance

Body weight and feed intake were measured at d 42, d 63, d 84,and d 105 by the cage. The average daily feed intake (ADFI), average daily gain (ADG), and gain to feed ratio (G:F) were calculated for each replicate and for the periods 42 to 63 d, 64 to 84 d, 85 to 105 d, and throughout the study (i.e. 42 to 105 d).

Egg production traits

At the farm, the eggs were manually collected two times per day. The number, weight and volume of eggs were recorded at d 63, d 84 and d 105 by the cage. The egg production, number of produced eggs to feed ratio (N:F), weight of produced eggs, weight of produced eggs to feed ratio (W:F), average egg weight and average egg volume were calculated for each replicate and for the periods 42 to 63 d, 64 to 84 d, 85 to 105 d and throughout the study (i.e. 42 to 105 d). For the same periods, the egg shape index was also calculated by the following formula (Alkan et al. 2010):

$$\text{shapeindex} = \text{eggwidth}(\text{mm})/\text{egglength}(\text{mm}).$$

Statistical analysis

Data were tested for normality with the Shapiro–Wilk test and variance homogeneity with the Levene's test before statistical analysis. Then, data were analysed according to a completely randomised design using the GLM procedure of SAS (2003) according to the model reported below:

$$Y_{ijk} = \mu + \text{vitamin E}_i + \text{vitamin C}_j + (\text{vitamin E} \times \text{vitamin C})_{ij} + e_{ijk},$$

where Y_{ijk} = the response variable, μ = overall mean, vitamin E_i = fixed effect of dietary level of vitamin E ($i = 3$; being 600, 800 and 1000 mg/kg), vitamin C_j = fixed effect of dietary level of vitamin C ($j = 3$; being 600, 800 and 1000 mg/kg), (vitamin E × vitamin C)$_{ij}$ = first-order interaction of main tested fixed effects, and e_{ijk} = random residual error. The growth performance parameters and egg productions traits were analysed both within experimental periods (i.e. 42 to 63 d, 64 to 84 d or 85 to 105 d) and on whole period (i.e. 42 to 105 d). Post hoc least-squares means tests were performed with the LSMEANS option of SAS (2003), using the Tukey method for multiple testing correction. The experimental unit was the pen. Significance was considered at $p \leq .05$ and tendency was declared at $0.05 < p \leq .10$.

Results

Growth performance

The effects of different supra-nutritional levels of vitamin E and C on growth performance of Japanese quails are shown in Table 2.

Effects of interaction between vitamin E and C were observed on BW, ADFI, ADG, and G:F. As reported by Sigolo et al. (2018), after 42 d of trial the highest BW ($p < .01$) were obtained with 1000 mg/kg of both vitamin E and C. After 63 ($p < .01$) and 84 d ($p = .05$), the highest BW were achieved with levels of vitamin E plus C of 800 and/or 1000 mg/kg. However, the highest final BW (i.e. 105 d; $p = .02$) was exclusively obtained with 1000 mg/kg of both the vitamins.

In the 42 to 63 d period, the highest ADFI (i.e. 704.55 g; $p < .01$) was observed at 800 mg/kg of vitamin E and 1000 mg/kg of vitamin C, whereas in the 64 to 84 d period at 800 mg/kg of both vitamin E and C (i.e. 745.35 g; $p < .01$). In the 85 to 105 d period, no treatment effects were observed on ADFI. Throughout the study (i.e. 42 to 105 d), a vitamin C effect ($p = .01$) was found on ADFI with the highest value observed at 800 mg/kg level (i.e. 2175.77 g).

The highest ADG were achieved with: 800 mg/kg of vitamin E plus 800 or 1000 mg/kg of vitamin C in the 42 to 63 d period ($p < .01$); 600 mg/kg of vitamin E plus 600 or 800 mg/kg of vitamin C in the 64 to 84 d period (i.e. 26.08 and 25.55 g; $p = .04$); 1000 mg/kg of vitamin E plus 600 mg/kg of vitamin C in the 85 to 105 d period (i.e. 21.38 g; vitamin E × C interaction, tendency $p = .06$); and 800 mg/kg of both the vitamins throughout the study (i.e. 100.63 g; vitamin E × C interaction, tendency $p = .06$).

The highest G:F values were observed at 800 mg/kg of vitamin E plus 800 or 1000 mg/kg of vitamin C in the 42 to 63 d period (i.e. 0.094; $p < .01$) and at 600 mg/kg of both the vitamins in the 64 to 84 d period (i.e. 0.037; $p = .03$). In the 85 to 105 d period, vitamin E and vitamin C effects ($p < .01$) were found on G:F. In particular, the supplementation of the diet with vitamin E at 600 or 1000 mg/kg level or vitamin C at 600 mg/kg level resulted in the highest G:F. Throughout the study, a vitamin E × C interaction effect (tendency, $p = .06$) was found on G:F with the highest values observed at the following levels of vitamins: 600 mg/kg of vitamin E plus 600 or 1000 mg/kg of vitamin C (i.e. 0.047) and 800 mg/kg of vitamin E plus 600 or 800 mg/kg of vitamin C (i.e. 0.047 and 0.046, respectively).

Egg production traits

The effects of different supra-nutritional levels of vitamin E and C on egg production traits of Japanese quails are shown in Table 3.

In the 42 to 63 d period ($p = .03$) and throughout the study ($p = .04$), a vitamin E × C interaction effect was found on egg production with the highest number of eggs achieved with 1000 mg/kg of both the vitamins (i.e. 138 and 504, respectively). In the 64 to 84 d period, the highest number of eggs was obtained with 1000 mg/kg of vitamin E or C, whereas in the 85 to 105 d period with 1000 mg/kg of vitamin E (i.e. 190) or 800 or 1000 mg/kg of vitamin C (vitamin E and vitamin C, $p < .01$).

In the 42 to 63 d (vitamin E and vitamin C, $p < .01$) and 85 to 105 d (vitamin E and vitamin C, $p = .01$) periods, and throughout the study (vitamin E and vitamin C, $p < .01$), the highest N:F ratios, were obtained with 1000 mg/kg of vitamin E (i.e. 0.188, 0.258, and 0.224, respectively in the three periods) or C (i.e. 0.193, 0.259, and 0.228, respectively). In the 64 to 84 d

Table 2. Growth performance of Japanese quails fed diets with different dietary levels of vitamin E and C.

Treatment		BW, g				ADFI, g				ADG, g				G:F			
Vitamin E, mg/kg	Vitamin C, mg/kg	42d	63d	84d	105d	42 to 63d	64 to 84d	85 to 105d	42 to 105d	42 to 63d	64 to 84d	85 to 105d	42 to 105d	42 to 63d	64 to 84d	85 to 105d	42 to 105d
600	600	195.650^{f}	248.980^{c}	275.050^{c}	295.630^{e}	680.350^{de}	714.150^{de}	733.850	2128.35	53.330^{e}	26.080^{a}	20.580^{ab*}	99.980^{ab*}	0.0790^{d}	0.0370^{a}	0.0280	0.0470^{a}
600	800	196.750^{ef}	251.380^{c}	276.930^{bc*}	296.730^{e}	679.600^{e}	714.730^{de}	781.500	2175.83	54.630^{de}	25.550^{a}	19.800^{ab*}	99.980^{ab*}	0.0810^{d}	0.0360^{ab*}	0.0250	0.0460^{ab*}
600	1000	197.050^{ef}	257.280^{b}	278.800^{b}	297.030^{de}	674.400^{e}	723.030^{cd*}	739.280	2136.70	60.230^{bc}	21.530^{abc}	18.230^{abc}	99.980^{ab}	0.0890^{ab}	0.0300^{bcd*}	0.0250	0.0470^{a}
800	600	197.300^{ef}	257.100^{b}	276.850^{bc}	296.880^{e}	683.080^{cde*}	711.080^{e}	740.850	2135.00	59.800^{bc}	19.750^{bc}	20.030^{ab}	99.580^{ab}	0.0870^{bc}	0.0280^{cd*}	0.0270	0.0470^{a}
800	800	198.230^{de}	263.730^{a}	282.800^{a}	298.850^{c}	693.700^{abc}	745.350^{a}	735.200	2174.25	65.500^{a}	19.080^{c}	16.050^{cd}	100.630^{a}	0.0940^{a}	0.0260^{d}	0.0220	0.0460^{a}
800	1000	199.600^{cd}	266.180^{a}	284.530^{a}	298.400^{cd}	704.550^{a}	726.980^{bc}	727.380	2158.90	66.580^{a}	18.350^{c}	13.880^{d}	98.800^{ab}	0.0940^{a}	0.0250^{d}	0.0190	0.0460^{ab}
1000	600	201.480^{b}	258.330^{b}	278.150^{bc}	299.530^{bc}	691.150^{bcd}	736.380^{ab}	712.950	2140.48	56.850^{cde}	19.830^{bc}	21.380^{a}	98.050^{bc}	0.0820^{cd}	0.0270^{cd}	0.0300	0.0460^{ab}
1000	800	201.250^{bc}	258.550^{b}	282.350^{a}	300.580^{b}	696.700^{ab}	734.780^{ab}	745.750	2177.23	57.300^{bcd}	23.800^{ab}	18.230^{abc}	99.330^{ab}	0.0830^{cd}	0.0320^{abc}	0.0250	0.0450^{ab}
1000	1000	205.480^{a}	265.950^{a}	284.400^{a}	302.250^{a}	701.050^{ab}	730.680^{bc}	748.630	2180.35	60.480^{b}	18.450^{c}	17.850^{bc}	96.780^{c}	0.0860^{bc}	0.0250^{d}	0.0240	0.0450^{b}
Main effect																	
Vitamin E																	
600		196.480	252.540	276.930	296.460	678.120	7.17.300	751.540	2146.96	56.060	24.380	19.530	99.980	0.0830	0.0340	0.0260^{a}	0.0470
800		198.380	262.330	281.390	298.040	693.780	727.800	734.480	2156.05	63.960	19.060	16.650	99.670	0.0920	0.0260	0.0230^{b}	0.0460
1000		202.730	260.940	281.630	300.780	696.300	733.940	735.780	2166.02	58.210	20.690	19.150	98.050	0.0840	0.0280	0.0260^{a}	0.0450
Vitamin C																	
600		198.140	254.800	276.680	297.340	684.860	720.530	729.220	2134.61^{b}	56.660	21.880	20.660	99.200	0.0830	0.0310	0.0280^{a}	0.0470
800		198.740	257.880	280.690	298.720	690.000	731.620	754.150	2175.77^{a}	59.140	22.810	18.030	99.980	0.0860	0.0310	0.0240^{b}	0.0460
1000		200.710	263.130	282.580	299.230	693.330	726.890	738.430	2158.65^{ab}	62.430	19.440	16.650	98.520	0.0900	0.0270	0.0220^{b}	0.0460
SEM		0.366	0.690	0.711	0.315	2.325	2.254	14.678	15.50	0.749	0.968	0.694	0.412	0.0012	0.0014	0.0010	0.0003
p-values																	
Vitamin E		<.010	<.010	<.010	<.010	<.010	<.010	.300	.33	<.010	<.010	<.010	<.010	<.0100	<.0100	<.0100	<.0100
Vitamin C		<.010	<.010	<.010	<.010	<.010	<.010	.130	.01	<.010	<.010	<.010	<.010	<.0100	<.0100	<.0100	.0300
Vitamin E × C		<.010	<.010	.050	.020	<.010	<.010	.230	.73	<.010	.040	.060	.060	<.0100	.0300	.1400	.0600

BW, body weight; ADFI, average daily feed intake; ADG, average daily gain; G:F, gain to feed ratio.
[a,b,c,d,e,f]Means within a column with different superscript letters differ ($p \leq .05$).

Table 3. Egg production traits of Japanese quails fed diets with different dietary levels of vitamin E and C.

Treatment		Number of produced eggs				N:F				Weight of produced eggs, g				W:F			
Vitamin E, mg/kg	Vitamin C, mg/kg	42 to 63d	64 to 84d	85 to 105d	42 to 105d	42 to 63d	64 to 84d	85 to 105d	42 to 105d	42 to 63d	64 to 84d	85 to 105d	42 to 105d	42 to 63d	64 to 84d	85 to 105d	42 to 105d
600	600	116.00^{f}	151.00	177.00	445.00^{e}	0.1710	0.2120^{d}	0.2420	0.2090	1398.00^{g}	1835.00	2153.00	5385.00^{e}	2.0550	2.5690^{c}	2.9340	2.5300
600	800	124.00^{d}	157.00	184.00	465.00^{cd}	0.1820	0.2200^{bcd}	0.2360	0.2140	1494.00^{de}	1923.00	2227.00	5643.00^{cd}	2.1990	2.6900^{abc}	2.8600	2.5950
600	1000	129.00^{c}	160.00	186.00	475.00^{c}	0.1920	0.2210^{bcd}	0.2520	0.2220	1554.00^{cd}	1948.00	2247.00	5748.00^{c}	2.3040	2.6940^{abc}	3.0390	2.6900
800	600	117.00^{ef}	151.00	177.00	445.00^{e}	0.1710	0.2130^{d}	0.2380	0.2080	1406.00^{fg}	1834.00	2133.00	5373.00^{bc}	2.0590	2.5790^{c}	2.8800	2.5170
800	800	132.00^{cb}	162.00	187.00	481.00^{bc}	0.1900	0.2170^{cd}	0.2550	0.2210	1588.00^{bc}	1959.00	2264.00	5811.00^{e}	2.2900	2.6290^{bc}	3.0790	2.6730
800	1000	135.00^{ab}	168.00	194.00	497.00^{ab}	0.1920	0.2310^{ab}	0.2670	0.2300	1637.00^{ab}	2021.00	2351.00	6009.00^{ab}	2.3240	2.7800^{ab}	3.2330	2.7830
1000	600	122.00^{ed}	155.00	181.00	458.00^{de}	0.1770	0.2100^{d}	0.2540	0.2140	1471.00^{ef}	1873.00	2191.00	5534.00^{de}	2.1280	2.5430^{c}	3.0720	2.5850
1000	800	134.00^{abc}	166.00	195.00	495.00^{ab}	0.1920	0.2260^{abc}	0.2620	0.2270	1617.00^{ab}	2018.00	2357.00	5991.00^{ab}	2.3210	2.7470^{ab}	3.1720	2.7540
1000	1000	138.00^{a}	172.00	194.00	504.00^{a}	0.1970	0.2350^{a}	0.2600	0.2310	1664.00^{a}	2074.00	2350.00	6088.00^{a}	2.3730	2.8390^{a}	3.1480	2.7930
Main effect																	
Vitamin E																	
600		123.00	156.00^{c}	182.00^{b}	462.00	0.1810^{b}	0.2180	0.2430^{b}	0.2150^{b}	1482.00	1902.00^{b}	2209.00^{b}	5592.00	2.1860^{c}	2.6510	2.9440^{b}	2.6050^{b}
800		128.00	160.00^{b}	186.00^{ab}	474.00	0.1840^{b}	0.2200	0.2530^{ab}	0.2200^{ab}	1544.00	1938.00^{b}	2249.00^{b}	5731.00	2.2240^{b}	2.6630	3.0640^{ab}	2.6580^{ab}
1000		131.00	164.00^{a}	190.00^{a}	485.00	0.1880^{a}	0.2240	0.2580^{a}	0.2240^{a}	1584.00	1988.00^{a}	2299.00^{a}	5871.00	2.2740^{a}	2.7100	3.1310^{a}	2.7110^{a}
Vitamin C																	
600		118.00	153.00^{c}	178.00^{b}	449.00	0.1730^{c}	0.2120	0.2440^{b}	0.2100^{c}	1425.00	1846.00^{b}	2159.00^{b}	5431.00	2.0800^{c}	2.5630	2.9620^{b}	2.5440^{c}
800		130.00	162.00^{b}	189.00^{a}	480.00	0.1880^{b}	0.2210	0.2510^{ab}	0.2210^{b}	1566.00	1967.00^{a}	2282.00^{a}	5815.00	2.2700^{b}	2.6890	3.0370^{ab}	2.6740^{b}
1000		134.00	167.00^{a}	191.00^{a}	492.00	0.1930^{a}	0.2290	0.2590^{a}	0.228^{a}	1618.00	2014.00^{a}	2316.00^{a}	5948.00	2.3330^{a}	2.7710	3.1400^{a}	2.7560^{a}
SEM		1.10	2.00	2.00	3.60	0.0015	0.0029	0.0058	0.0027	14.10	22.50	24.40	44.40	0.0187	0.0331	0.0706	0.0317
p-values																	
Vitamin E		<.01	<.01	<.01	<.01	<.0100	.0400	.0100	<.0100	<.01	<.01	<.01	<.01	<.0100	.0900	.0100	<.0100
Vitamin C		<.01	<.01	<.01	<.01	<.0100	<.0100	.0100	<.0100	<.01	<.01	<.01	<.01	<.0100	<.0100	.0200	<.0100
Vitamin E × C		.03	.25	.14	.04	.1100	.0500	.1700	.3200	.05	.36	.11	.04	.2000	.0400	.1500	.3200

Treatment		Average egg weight, g/egg				Average egg volume, cc/egg[1]				Egg shape index[2]			
Vitamin E, mg/kg	Vitamin C, mg/kg	42 to 63d	64 to 84d	85 to 105d	42 to 105d	42 to 63d	64 to 84d	85 to 105d	42 to 105d	42 to 63d	64 to 84d	85 to 105d	42 to 105d
600	600	12.030	12.130	12.150	12.110	11.2^{f}	12.7^{f}	13.8^{f}	12.6^{g}	0.4400^{c}	0.4900	0.5250	0.4850
600	800	12.100	12.230	12.120	12.150	11.9^{de}	14.0^{de}	15.3^{de}	13.7^{de}	0.4430^{bc}	0.4850	0.5330	0.4880
600	1000	12.020	12.180	12.080	12.100	12.0^{d}	14.1^{de}	15.8^{cd}	14.0^{cd}	0.4400^{c}	0.4900	0.5380	0.4880
800	600	12.040	12.120	12.090	12.090	11.5^{ef}	13.1^{f}	14.1^{f}	12.9^{f}	0.4500^{b}	0.4980	0.5480	0.4980
800	800	12.060	12.110	12.090	12.090	12.4^{c}	14.4^{cd}	15.9^{bc}	14.2^{c}	0.4550^{bc}	0.5050	0.5600	0.5030
800	1000	12.130	12.030	12.120	12.090	12.9^{ab}	14.9^{ab}	16.4^{ab}	14.7^{ab}	0.4500^{b}	0.5050	0.5600	0.5030
1000	600	12.060	12.080	12.120	12.090	11.9^{de}	13.8^{e}	15.1^{e}	13.6^{e}	0.4500^{b}	0.5000	0.5580	0.5030
1000	800	12.090	12.140	12.120	12.12	12.7^{bc}	14.7^{bc}	16.2^{abc}	14.6^{b}	0.4450^{bc}	0.5050	0.5650	0.5050
1000	1000	12.050	12.080	12.130	12.090	13.1^{a}	15.8^{a}	16.7^{a}	15.1^{a}	0.4600^{a}	0.5180	0.5700	0.5180
Main effect													
Vitamin E													
600		12.050	12.180	12.110	12.120	11.67	13.60	14.93	13.41	0.4410	0.4880^{b}	0.5320^{c}	0.4870^{c}
800		12.070	12.090	12.100	12.090	12.26	14.13	15.44	13.93	0.4480	0.5030^{a}	0.5560^{b}	0.5010^{b}
1000		12.070	12.100	12.120	12.100	12.54	14.63	15.99	14.40	0.4520	0.5080^{a}	0.5640^{a}	0.5080^{a}
Vitamin C													
600		12.040	12.110	12.120	12.090	11.52	13.20	14.33	13.02	0.4470	0.4960^{b}	0.5430^{b}	0.4950^{b}
800		12.080	12.160	12.110	12.120	12.32	14.34	15.78	14.14	0.4440	0.4980^{ab}	0.5530^{a}	0.4980^{ab}
1000		12.070	12.100	12.110	12.090	12.63	14.81	16.27	15.58	0.4500	0.5040^{a}	0.5560^{a}	0.5030^{a}
SEM		0.038	0.052	0.026	0.023	0.08	0.11	0.17	0.07	0.0016	0.0035	0.0032	0.0029
p-values													
Vitamin E		.660	.080	.540	.310	<.01	<.01	<.01	<.01	<.010	<.010	<.010	<.010
Vitamin C		.450	.310	.890	.360	<.01	<.01	<.01	<.01	<.010	.020	<.010	.010
Vitamin E × C		.390	.730	.450	.830	.02	.07	.09	.03	<.010	.110	.890	.140

N:F, number of produced eggs to feed ratio; W:F, weight of produced eggs to feed ratio.
[1]Number of samples= 10 eggs/replicate.
[2]Egg width/egg length; number of samples= 5eggs/replicate.
[a,b,c,d,e,f]Means within a column with different superscript letters differ ($p \leq 0.05$).

period, a vitamin E × C interaction effect ($p = .05$) was found on N:F with the highest value (i.e. 0.235) observed at 1000 mg/kg of both the vitamins.

A vitamin E × C interaction effect was found on the weight of produced eggs in the 42 to 63 d period ($p = .05$) and throughout the study ($p = .04$) with the highest weights observed at 1000 mg/kg of both the vitamins (i.e. 1664 and 6088 g, respectively). In the 64 to 84 d and 85 to 105 d periods, there were vitamin E and vitamin C effects ($p < .01$) and the highest egg weights were obtained with 1000 mg/kg of vitamin E or 800 or 1000 mg/kg of vitamin C.

The highest W:F ratios were achieved with: 1000 mg/kg of vitamin E or C in the 42 to 63 d (vitamin E and vitamin C, $p < .01$) and 85 to 105 d (i.e. 3.131, vitamin E, $p = .01$; 3.140, vitamin C, $p = .02$) periods, and throughout the study (i.e. 2.711 and 2.756, vitamin E and vitamin C, $p < .01$). A vitamin E × C interaction effect was found on W:F in the 64 to 84 d period ($p = .04$) with the highest value (i.e. 2.839) observed at 1000 mg/kg of both the vitamins.

No treatment effects were observed on average egg weight. In all the considered periods, a vitamin E × C interaction effect was found on average egg volume with the highest values (i.e. 13.1 cc/egg in the 42 to 63 d period, $p = .02$; 15.8 cc/egg in the 64 to 85 d period, tendency $p = .07$; 16.7 cc/egg in the 85 to 105 d period, tendency $p = .09$; and 15.1 cc/egg for the 42 to 105 d period, $p = .03$) obtained supplementing the quail diet with 1000 mg/kg of both the vitamins.

A vitamin E × C interaction effect was also found on egg shape index in the 42 to 63 d period ($p < .01$) with the highest value observed at 1000 mg/kg of both the vitamins. In the other three periods, there were effects of vitamin E and vitamin C on egg shape index. In particular, in the 64 to 84 d period (vitamin E, $p < .01$; vitamin C, $p = .02$), the highest values were obtained with 800 or 1000 mg/kg of vitamin E or 1000 mg/kg of vitamin C (i.e. 504); in the 85 to 105 d period (vitamin E and vitamin C, $p < .01$) with 1000 mg/kg of vitamin E or 800 or 1000 mg/kg of vitamin C; and throughout the study (vitamin E, $p < .01$; vitamin C, $p = .01$), with 1000 mg/kg of vitamin E or C.

Discussion

Growth performance

Current results showed that dietary supplementation with vitamin E and C may positively affect the growth performance of Japanese quails during the egg production period under controlled environmental conditions. Taking into account all the parameters of growth performance obtained throughout the study (i.e. from d 42 to d 105), it emerges that feed intake, weight gain, and dietary efficiency were at the same time improved by using a combination of vitamin E and C both at the level of 800 mg/kg. However, the quails fed the diet supplemented with both the vitamins at the highest tested dose (1000 mg/kg) raised the highest weights at the end of the trial. In agreement with our findings, Sahin and Kucuk (2001), and Ipek and Dikmen (2014) found that high dietary level of vitamin E and C resulted in increased body weight of quails. Previous studies have demonstrated that dietary supplementations with vitamin E and C, alone or in combination, may improve growth performance of quails reared under heat stress condition (Sahin et al. 2002b; Ipek et al. 2007; Hemid et al. 2010). Stressful conditions, such as high environmental temperature, bring to the formation of cell-damaging cytotoxic free radicals, increased protein catabolism and reduced protein biosynthesis, and depletion of vitamin C (Ipek et al. 2007). Therefore, in poultry nutrition, vitamin E and C, thanks to their antioxidant properties, play a key role in the alleviating some of the physiological responses and improving thermotolerance (Sahin and Kucuk 2001; Çiftçi et al. 2005; Ipek et al. 2007). In particular, vitamin C promotes performance associated with the suppressed-stress responses as indicated by lowering the plasma corticosterone level and adrenocorticotropic hormone (Lin et al. 2006; Ahmadu et al. 2016). Nevertheless, it has been suggested that vitamin C effectiveness on poultry performance expresses only in environmental stress condition whereas is not detectable under normal temperature condition (Newman and Leeson 1999; Saki et al. 2010). However, there is growing evidence that the interaction between the two major antioxidant vitamins (i.e. E and C) is also of pathophysiological importance (Subasree 2014). Oxidative lesions, leading to conformational modifications of proteins, could induce pancreatic enzyme inhibition and/or dietary protein resistance to digestion (Ahmadu et al. 2016). Consequently, antioxidants, such as vitamin E and/or C, could contribute in preserving the proteins from oxidative denaturation improving digestibility of nutrients and their metabolic utilisation (Panda et al. 2008; Ahmadu et al. 2016). As already observed in our previous study (Sigolo et al. 2018), under thermoneutral condition, vitamin E and C added together at high doses (1000 mg/kg) to quail diet seem to interact in promoting a general animals' welfare which results in raised growth.

Egg production traits

Taking into account all the results related to the egg production traits obtained throughout the study (i.e. from d 42 to d 105), it emerges that dietary supplementation with a combination of vitamin E and C both at 1000 mg/kg level increased egg production, weight of produced eggs, N:F and W:F ratios, average egg volume, and egg shape index. However, similar results were also obtained by a combination of vitamin E at 800 mg/kg level and C at 1000 mg/kg level. In agreement with our findings, several studies have reported increased egg production when Japanese quails fed diets supplemented with vitamin E and/or C (Bardakcioglu et al. 2005; Sahin et al. 2006; Ajakaiye et al. 2010; Caurez and Olo 2013; Abedi et al. 2017). In the current study, although the dietary addition of vitamin E plus C raised the total weight of produced eggs, no treatment effect was observed on the average egg weight in disagreement with Ipek and Dikmen (2014). Nevertheless, Bardakcioglu et al. (2005) suggested that vitamin C supplementation seem to have no prominent effect on egg weight. However, in our study higher average egg weights were obtained compared with to those found by Bardakcioglu et al. (2005), and Ipek and Dikmen (2014). The increased egg shape indices, obtained throughout our study by supplementing quail diet with vitamin E or C, were in contrast with Chitra et al. (2016). The latter found no effect of dietary supplementation with vitamin E on egg shape index. The literature is still controversial about the effects of vitamin E and/or C on the egg production traits. However, the reported discrepancies could depend on to the different conditions of work, such as dose of vitamin E and/or C used and environmental temperature. On the base of our results, it deduces that vitamin E and C, added together to the diet of quails at high doses, can improve egg production traits under thermoneutral environmental condition.

Conclusions

Current findings showed that feeding vitamin E and C at supra-nutritional levels can be a good management practice in Japanese quail nutrition to promote growth performance and egg production traits under thermoneutral environmental condition. When these vitamins are added together to quail diet, both at high doses (1000 mg/kg), they seem synergistically act in promoting animal growth. Dietary supplementation with vitamin E at 800 or 1000 mg/kg level plus vitamin C at 1000 mg/kg could improve egg production traits in terms of egg production, total weight of produced eggs, N:F and W:F ratios, average egg volume, and egg shape index.

Disclosure statement

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