Received: 30 August 2017 | Accepted: 30 December 2017

DOI: 10.1111/jpn.12873

ORIGINAL ARTICLE

WILEY Journal of Animal Physiology and Animal Nutrition

The effects of dietary calcium iodate on productive performance, egg quality and iodine accumulation in eggs of laying hens

R. Bakhshalinejad | A. Hassanabadi | H. Nassiri-Moghaddam | H. Zarghi

Department of Animal Science, Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran

Correspondence
A. Hassanabadi, Department of Animal Science, Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran.
Email: hassanabadi@um.ac.ir

Funding information
Ferdowsi University of Mashhad

Summary

The aim of this study was to examine the effects of various levels of supplemental calcium iodate (CI) on productive performance, egg quality, blood indices and iodine (I) accumulation in the eggs in commercial laying hens. A total of 240 White Leghorn layers (Hy-line W36) were divided through a completely randomized design into six treatments with five replicates and eight hens per each at 32 weeks of age. This experiment lasted for 12 weeks. Concentrations of I in the mash diets were 0.74, 3.13, 5.57, 8.11, 10.65 and 12.94 mg I/kg of feed in treatments 1–6 respectively. The added doses of CI were included 0.0 (control), 2.5, 5.0, 7.5, 10.0 and 12.5 mg/kg of diet for treatments 1–6 respectively. There were no significant differences in productive performance among the treatments. The highest eggshell strength was observed in group fed diet containing 3.13 mg I/kg (p = .014). The highest percentage of calcium and lowest percentage of phosphorus in eggshell were observed in group fed diet containing 12.94 mg I/kg (p = .0001). Feeding hens with diet containing 12.94 mg I/kg increased serum triiodothyronine-to-thyroxine ratio (p = .0001). Serum alanine aminotransferase activity in hens fed diet containing 12.94 mg I/kg was significantly more than control (p = .041). Blood Serum triglycerides in hens fed diet containing 8.11 mg I/kg were significantly higher than control (p = .0001). Edible fraction of the eggs of birds fed diet containing 12.94 mg I/kg was enriched by I almost 3 times more than those fed diet containing 0.74 mg I/kg. The results suggested that egg production, egg mass, feed intake and feed conversion ratio were not significantly affected by dietary I levels. Iodine accumulation in the eggs were increased by increasing dietary I levels and the level of 10 mg/kg CI could supply I enrichment of the eggs.

KEYWORDS

blood indices, egg production, egg quality, iodine, iodine accumulation, laying hens

1 | INTRODUCTION

Iodine (I) is an essential trace element for humans and animals. It is required for biosynthesis of thyroid hormones, that is triiodothyronine (T_3) and thyroxine (T_4), and also iodinated molecules of the amino acid tyrosine. Principal function of T_4 is to control of cellular oxidation as well as playing significant roles in the pituitary gland and gonads (Proudman & Siopes, 2002). Thyroid hormones perform important roles in the regulation of cholesterol levels in humans and animals (Mathe & Chevallier, 1976). Iodine deficiency leads to functional change of thyroid gland and reduction of T_4 synthesis, endemic goitre, endemic cretinism, abortion, preventable intellectual impairment and probably thyroid cancer (Goldhaber, 2003; McDowell, 1992). Iodine ion is freely diffusible and readily absorbed from gastrointestinal tract

 © 2018 Blackwell Verlag GmbH

and is excreted mainly in urine at a relatively constant rate when I is being sufficiently supplemented into diet (Soetan, Olaiya, & Oyewole, 2010).

The World Health Organization (WHO) has declared that I is one of the most important food components affecting consumers' health. It is estimated that 43 millions people are suffering from psychical disorders caused by maternal I deficiency during pregnancy. Based on the WHO estimation, over 280 millions school-age children have I intake below the required level, which is 120 μg per day (Andersson, De Benoist, Darnton-Hill, & Delange, 2007; De Benoist, McLean, Andersson, & Rogers, 2008).

The prevention of I deficiency disorders is possible by supplementing foods with I (Dunn, 2003; Laurberg, 2004). However, enrichment of the common salt with I has been successfully achieved and some other examples listed as fortification of tea, drinking water, fish paste, bread, sugar, milk and meat (Bourre & Galea, 2006; Nestel, 1993; Phillips, 1997). Enriched eggs with I is being considered as a easily available source of I in human food basket (Bourre & Galea, 2006).

Iodine is a very important microelement for laying hens too. This microelement is a component of thyroxin hormone, which regulates body metabolism and it has a strong influence on growth and performance of the hens (Lewis, 2004). The avian thyroid gland is similar to the mammalian one in all aspects. Deficiency of I can cause metabolic disorders, decreased hatchability and laying rate, and abnormal enlargement of the thyroid gland named goitre (Lewis, 2004). Excess dietary I will also cause hatchability problems, embryonic mortality, unhatched pips and extended incubation periods (Lichovnikova & Zeman, 2004).

In the poultry diets, available sources of I in addition to feed sources are mainly sodium iodide (NaI), potassium iodide (KI), potassium iodate (KIO_3) and calcium iodate ($Ca(IO_3)_2$) that are being mixed into mineral premix, or into iodized salt. Potassium iodide is very unstable and spoils quickly with moderate exposure to heat, light and moisture. Calcium iodate (CI) is the most common source of supplemental I (Leeson & Summers, 2009). Ammerman and Miller (1972) reported that the bioavailability of CI is approximately 95% in poultry.

The aim of the present study was to examine the effects of various levels of CI as I supplemental source in diet of laying hens on productive performance, egg quality, blood indices and enrichment of the eggs.

2 | MATERIALS AND METHODS

2.1 | Birds and management

This study was performed in the Poultry Research Station of Ferdowsi University of Mashhad (Mashhad, Iran), and all procedures used were approved by the Ferdowsi University of Mashhad Animal Care and Use Committee.

A total of 240 White Leghorn layer hens (Hy-line W36) at 30 weeks of age were chosen from a large flock based on similar weights and production rates with an initial average body weight of 1,520 ± 10 g. The hens were randomly distributed into battery cages (four hens per cage, 60 cm length × 60 cm width × 40 cm height) among six treatments with five replicates and eight hens per each replicate. Each cage was equipped with a feeding trough and a nipple drinker. Feed and water were provided ad libitum throughout the experiment. The house temperature and the lighting program were set in the range of 16–20°C and 16 light:8 dark during the experiment respectively. Experimental period was included a 2-week adaptation phase (30–32 weeks of age) and 12 weeks of data collection (32–44 weeks of age).

2.2 | Diets and analytical methods in diet

The basal experimental diet (Table 1) was formulated to provide all nutrients specified by Hy-Line W36 recommendations (Hy-Line International, 2015) with exception of I level. The levels of added I and concentrations of I in the basal mash diets are shown in Table 2. Source of supplemental I was CI (98.5% purity, containing 65% I) that was purchased from BDH (BDH Chemicals, Poole, UK). For preparing a homogenous mixture of I within the feed, CI was firstly added to mineral premix and then was added to other major ingredients.

The chemical composition of feed ingredients and also complete feed mixtures was determined according to AOAC (2000). Feed samples were ground in a laboratory mill provided with a 1-mm screen and analysed for dry matter (DM, method 930.15), total ash (method 942.05) and crude protein (CP, Kjeldahl $N \times 6.25$, method 990.03). Calcium (Ca) content in basal diet was analysed with Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) instrument (Spectro Arcos, Kleve, Germany; method 968.08). Digestible amino acids of feed ingredients (with the using of NIR) were analysed by Evonik-Degussa (Kennesaw, GA). Iodine contents of the experimental diets were measured by a spectrophotometric method based on the Sandell–Kolthoff reaction (Dyrka, Drożdż, Naskalski, Szybiński, & Franek, 2011).

2.3 | Performance and egg quality traits

Hens were weighed individually by digital balance at the beginning and end of the experiment to determine body weight changes. All the eggs produced were collected at the same time daily (7:00 p.m.) and classified as normal or damaged (broken, cracked, or shell-less eggs) by visually checking throughout the experiment. Egg production was calculated on a hen-day basis. Moreover, Hens mortality was recorded as it occurred. All eggs in each replicate were weighed individually by digital balance on the same day of each week (0.001-g digital balance, model GF 400, A&D Weighing, CA).

Feed intake was calculated considering the difference of given feed at the beginning and during each week and remained feed in the feeders at the end of the week. Egg mass production was calculated by multiplying egg weight (g) by hen-day egg production (%). Feed conversion ratio (FCR) was calculated as kg of feed per kg of egg mass.

To determine egg quality, 15 eggs were randomly collected from each treatment (three eggs per replicate) at three weekly intervals. Egg specific gravity (g/cm^3) was determined by Archimedes method (Hempe, Laukxen, & Savage, 1988). Individual eggs were weighed

TABLE 1 Composition of the experimental basal diet

Item	Amount
Ingredient, g/kg as-fed basis	
Corn grain	605.5
Soybean meal (440 g crude protein/kg)	232.1
Limestone	98.2
Soya bean oil	34.0
Dicalcium phosphate	18.9
Sodium chloride	4.1
Vitamin premix[a]	2.5
Mineral premix[b]	2.5
$_{DL}$-methionine	1.7
$_{L}$-threonine	0.4
$_{L}$-lysine HCL	0.1
Total	1,000
Nutritive value of mixtures, calculated, per kg	
Metabolizable energy, kcal (MJ)	2,900 (12.13)
Crude protein, g	155.0
Calcium, g	42.0
Available phosphorus, g	4.8
Digestible lysine, g	7.5
Digestible methionine, g	4.0
Digestible methionine + cystine, g	6.3
Digestible threonine, g	5.3
Nutritive value of mixtures, analysed, per kg	
Dry matter, g	879.9
Crude protein, g	154.9
Ash, g	130.8
Calcium, g	42.1
Digestible lysine, g	7.5
Digestible methionine, g	4.1
Digestible methionine + cystine, g	6.4
Digestible threonine, g	5.2
Iodine, mg	0.74

[a]Provides in kg of diet: vitamin A (retinol), 8,800 IU; vitamin D_3 (cholecalciferol), 3,300 IU; vitamin E ($_{DL}$-α-tocopheryl acetate), 18.5 IU; vitamin K_3 (menadione), 2.2 mg; vitamin B_1 (thiamin), 2.2 mg; vitamin B_2 (riboflavin), 5.5 mg; vitamin B_3 (niacin), 28.0 mg; vitamin B_5 (pantothenic acid), 6.6 mg; vitamin B_6 (pyridoxine), 3.5 mg; vitamin B_9 (folic acid), 0.7 mg; vitamin B_{12} (cyanocobalamin), 0.02 mg; vitamin H_2 (biotin), 0.05 mg; antioxidant 1.0 mg.
[b]Provides (mg/kg of diet): Mn (manganese sulphate) 88.0, Fe (iron sulphate) 55.0, Zn (zinc sulphate) 88.0, Cu (copper sulphate) 5.5, Se (sodium selenite) 0.3.

as well as the yolk, albumen and eggshell. Broken shells were rinsed under tap water and dried for 48 hr followed by determination of weight and thickness (Shafer, Carey, Prochaska, & Sams, 1998). Then yolk, albumen and eggshell percentage were calculated. Moreover egg width, egg length, yolk diameter, yolk height and albumen height were measured (0.01-mm digital calliper, model 1116-150, Insize, Suzhou, China) and then yolk and egg shape indices were calculated (Card & Nesheim, 1972). Haugh units were calculated based on formula: (Haugh units = 100 × $\log_{10}$ [albumen height (mm) − (1.7 × egg weight (g)^{037}) + 7.57]) (Haugh, 1937). Egg shell thickness was measured using a micrometer screw at three different locations (top, middle and bottom of the egg) and these three measurements were averaged to determine overall egg shell thickness (0.001-mm digital micrometer, model 293-240, Mitutoyo, Kanagawa, Japan; Carter, 1975). Eggshell breaking strength (N/cm^2) was determined using a Tinius Olsen Testing Machine (model H5KS, Tinius Olsen, Horsham, PA) equipped with a maximum 50-N load cell and speed of 1 mm/min. Egg yolk colour intensity was evaluated visually using a La Roche yolk colour fan scale (DSM Nutritional Products., Roche Basel, Switzerland). Egg quality analyses were completed within 12 hr of the eggs being collected.

Five gram of each eggshell samples was placed into aluminium dishes and then were moved to an oven at temperature of 105°C for 24 hr. Samples after removal from the oven were placed in a desiccator and were weighed immediately. Ash of the samples was determined by muffle furnace oven at 600°C for 6 hr (Wu, Bryant, Voitle, & Roland, 2005). The samples were digested with nitric and perchloric acids mixture and then were sent to Central Laboratory at Ferdowsi University of Mashhad (Mashhad, Iran) where mineral content such as Ca and total phosphorus (P) were determined using an Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) instrument (Spectro Arcos, Kleve, Germany).

TABLE 2 Dietary treatments, supplemental iodine and iodine concentration in diets (mg/kg)

Treatment	Iodine supplemental[a]	Iodine concentration[b]
1	0	0.74
2	2.5	3.13
3	5.0	5.57
4	7.5	8.11
5	10.0	10.65
6	12.5	12.94

[a]Iodine supplemented in form of calcium iodate.
[b]Iodine concentration in diets was analysed by a spectrophotometric method based on the Sandell–Kolthoff reaction (Dyrka et al., 2011).

2.4 | Blood collection and analysis

At the end of experiment, 15 hens were randomly selected from each treatment (three birds per replicate) and were designated for blood sampling. Blood samples were taken from the vena brachialis; 1.5 ml of blood was collected in K_2EDTA sterile syringe from each hen for biochemical analysis. Meanwhile, another 2 ml of blood samples was collected from each bird to determine blood serum indices. The following blood indices were measured using a Sysmex automated haematology analyzer (model KX21, Sysmex, Kobe, Japan): white blood cells number (WBC), red blood cells number (RBC), haemoglobin (HGB), haematocrit (HCT) and platelets (PLT).

Blood samples were centrifuged at 3,000 × *g* for 10 min under 4°C, and the sera were analysed for aspartate aminotransferase (AST), alanine aminotransferase (ALT), alkaline phosphatase (ALP), triglycerides (TG), total cholesterol (CHOL), high-density lipoproteins (HDL), low-density lipoproteins (LDL), T_3 and T_4. Biochemical indices in the blood sera were analysed by multitest automatic random-access system autoanalyzer (model 400 plus, Cobas integra Bio, Roche Basel, Switzerland).

2.5 | Determination of iodine content in eggs and excreta

At the end of the experiment, 15 eggs were randomly sampled from each treatment (three eggs per replicate). Then, I concentration in egg yolk, egg albumen, eggshell and whole egg (edible fraction) were determined by a spectrophotometer at 450 nm wavelength (UV-2100, Unico Instruments, Shanghai, China) after alkaline ashing according to the Sandell–Kolthoff reaction (Khazan, Azizi, & Hedayati, 2013). All reagents used in this method were purchased from Merck (Darmstadt, Germany).

At the end of experiment, excreta were collected from dropping belt under the cages. Feathers and feeds were carefully removed, and excreta were put into an oven drier to be dried at 60°C for 24 hr. Three average samples were prepared from each replicate. After drying, all samples were finely ground through a 1-mm screen to get representative samples then I concentration was determined (Benotti, Benotti, Pino, & Gardyna, 1965). Values for apparent retention of I, expressed as a percentage of I intake, were calculated by subtracting I excreted in the egg and excreta from I intake, dividing by I intake and multiplying the result by 100 (Pekel, Demirel, Alp, Kocabagli, & Acar, 2012).

2.6 | Statistical analysis

The experiment was conducted as a completely randomized design with six treatments, five replicates and eight hens per replicate. Data were tested for normality by UNIVARATE plot normal procedure. To test the effect of I concentrations on different parameters, the data were subjected to ANOVA using the GLM procedure of SAS software (SAS Institute, 2009). Differences among treatment means were tested for significance using Tukey's multiple-range test at a probability of $p < .05$ (Tukey, 1991). All numerical data in tables are presented as average values and are accompanied by *SEM* (standard error of the means) values (SAS Institute, 2009). The orthogonal polynomial contrast test was performed to determine linear and quadratic effects of increasing concentrations of I in the diets on performance, egg quality, blood and blood serum indices and I accumulation in the eggs of laying hens (SAS Institute, 2009).

3 | RESULTS

3.1 | Hens' performance

Productive performance of the laying hens including egg production, egg mass, feed intake and FCR was not significantly affected ($p > .05$) by dietary treatments (Table 3).

3.2 | Egg quality

Egg specific gravity, egg yolk percentage, egg albumen percentage, eggshell percentage, egg shape and egg yolk indices, Haugh unit and eggshell thickness were not significantly affected ($p > .05$) by dietary I levels (Table 4). Eggshell strength was significantly affected ($p = .014$)

TABLE 3 Effects of increasing concentrations of iodine in diet on performance of laying hens during 32–44 weeks of age[a]

	Iodine concentrations in diets (mg/kg)[b]							*p*-Value[c]		
Parameters	0.74	3.13	5.57	8.11	10.65	12.94	*SEM*	ANOVA	Linear	Quadratic
Hen-day egg production (%)	87.44	88.02	88.28	89.29	90.26	89.22	1.214	.617	.413	.668
Egg mass production (g day^{-1} hen^{-1})	52.43	52.73	52.81	52.86	53.39	52.59	0.898	.983	.816	.904
Egg weight (g/egg)	61.91	61.16	61.34	61.35	61.06	61.37	0.536	.910	.416	.501
Feed intake (g day^{-1} hen^{-1})	96.38	96.68	98.52	98 .37	95.37	97.39	1.620	.727	.610	.667
Feed conversion ratio (kg feed/kg egg mass)	1.84	1.83	1.88	1.86	1.80	1.85	0.049	.902	.862	.840
Un-normal eggs[d] (%)	0.91	0.89	0.85	0.85	0.79	0.65	0.229	.968	.860	.679
Body weight change (g)	12.20	10.40	12.80	13.00	17.00	14.80	24.731	1.000	.968	.998

SEM, Standard error of the means.
All differences among means were no significant.
[a]Each value represents the mean of five replicates with eight hens per replicate.
[b]Calcium iodate was supplemented at the level of 0.0, 2.5, 5.0, 7.5, 10.0 or 12.5 mg/kg to the diets respectively.
[c]*p* values for linear and quadratic effects of increasing concentrations of iodine in diets.
[d]Sush as broken, cracked or shell-less eggs.

TABLE 4 Effects of increasing concentrations of iodine in diet on the egg quality parameters of laying hens during 32–44 weeks of age[1]

	Iodine concentrations in diets (mg/kg)[2]							*p*-Value[3]		
Parameters	0.74	3.13	5.57	8.11	10.65	12.94	*SEM*	ANOVA	Linear	Quadratic
Egg specific gravity (g/cm^3)	1.082	1.083	1.085	1.083	1.083	1.084	0.001	.645	.249	.367
Egg yolk percentage (%)	25.54	26.45	25.64	26.06	26.10	25.99	0.422	.693	.612	.697
Egg albumen percentage (%)	64.90	63.88	64.47	64.29	64.22	64.27	0.390	.598	.367	.464
Eggshell percentage (%)	9.56	9.68	9.90	9.64	9.67	9.74	0.151	.726	.354	.417
Egg shape index (%)	76.76	76.43	76.43	76.23	77.09	76.04	0.502	.727	.982	.893
Egg yolk index (%)	44.19	43.38	44.28	44.05	43.40	44.74	0.652	.657	.377	.296
Egg yolk colour (Roche points)	6.92	6.48	6.40	6.66	7.15	6.83	0.173	.045	.197	.109
Egg Haugh unit	84.45	81.46	84.59	84.63	84.13	85.86	1.395	.254	.997	.668
Eggshell thickness (mm)	0.395	0.402	0.397	0.402	0.392	0.396	0.006	.738	.658	.593
Eggshell strength (N/cm^2)	38.87^{ab}	41.10^{a}	36.66^{ab}	40.86^{a}	35.77^{b}	37.56^{ab}	1.161	.014	.967	.719
Eggshell calcium (%)	34.29^{e}	33.52^{d}	34.99^{c}	36.54^{b}	37.18^{a}	37.21^{a}	0.102	.0001	.013	.872
Eggshell phosphorus (%)	0.108^{a}	0.105^{ab}	0.103^{bc}	0.101^{cd}	0.099^{ed}	0.096^{e}	0.001	.0001	.016	.674

SEM, Standard error of the means.
[a–e]Values within the same row with different superscript letters differ ($p < .05$).
[1]Each value represents the mean of five replicates with three hens per replicate.
[2]Calcium iodate was supplemented at the level of 0.0, 2.5, 5.0, 7.5, 10.0 or 12.5 mg/kg to the diets respectively.
[3]*p* values for linear and quadratic effects of increasing concentrations of iodine in diets.

by dietary treatments and the hens fed diet containing 3.13 mg I/kg, demonstrated higher eggshell strength compared with the eggs laid by hens fed diet containing 10.65 mg I/kg (41.10 vs. 35.77 N/cm^2).

As Ca and P are important components of eggshell, the effect of increasing dietary concentration of I on the level of Ca and P in eggshell was determined. Results revealed significant differences among the treatments. The highest percentage of Ca and the lowest percentage of P were observed in group fed diet containing 12.94 mg I, and lowest percentage of Ca and highest percentage of P were observed in group fed diet containing 0.74 mg I ($p = .0001$). The orthogonal contrast showed a linear relationship between eggshell Ca percentage and increasing dietary I concentration ($p < .05$).

3.3 | Blood and blood serum indices

The effects of increasing dietary I levels on blood and blood serum indices of the laying hens during 32–44 weeks of age are shown in Table 5. White blood cells count significantly affected by dietary treatments ($p = .039$), so that it was enhanced from 15.45 to 16.00 10^9/L by an increase in dietary I level from 0.74 to 12.94 mg I/kg of diet. Red blood cells numbers, HGB, HCT and PLT were not significantly differed among the treatments.

Blood sera concentrations of T_3, T_4 and T_3/T_4 ratio were significantly different among the treatments ($p = .0001$). The highest T_3 and lowest T_4 levels were observed in group fed diet containing 12.94 mg I, and so highest T_3/T_4 level was observed in group fed diet containing 12.94 mg I ($p = .0001$). The orthogonal contrasts showed that there is a significant linear and quadratic relation between T_3, T_4 and T_3/T_4 ratio and increasing dietary I levels ($p = .0001$).

Serum concentrations of AST, ALT and ALP were significantly different ($p = .021$, $p = .041$ and $p = .001$ respectively) among the treatments. Hens fed diet containing 12.94 mg I demonstrated higher AST activity compared to hens fed diet containing 3.13 mg I (218.56 vs. 237.63 U/L). Hens fed diet containing 12.94 mg I demonstrated higher ALT activity compared with hens fed diet containing 0.74 mg I (3.89 vs. 4.61 U/L). Also, hens fed diet containing 12.94 mg I demonstrated higher ALP activity compared with hens fed diet containing 8.11 mg I (409.01 vs. 475.40 U/L). The orthogonal contrast on serum AST and ALP concentrations showed a significant linear and quadratic effects between treatments and increasing dietary I concentrations ($p < .05$).

Triglycerides levels were significantly increased from 9.47 to 9.98 mmol/L by dietary I levels; so that hens fed diet containing 8.11 mg I demonstrated higher TG level compared with hens fed diet containing 0.74 mg I/kg ($p = .0001$). Total cholesterol levels were significantly increased from 3.33 to 3.97 mmol/L; so that hens fed diet containing 5.57 mg I demonstrated higher CHOL level compared with hens fed diet containing 0.74 mg I/kg ($p = .001$). The orthogonal contrast on TG and CHOL levels showed a significant linear and quadratic effects between treatments and increasing I concentration in diets ($p < .05$). Our findings elucidated that, although HDL and LDL did not significantly affect, but HDL/LDL ratio was significantly influenced among dietary treatments ($p = .041$).

3.4 | Iodine enrichment of the eggs

The effects of increasing dietary I concentrations on I intake, I accumulation in egg yolk, egg albumen, eggshell and whole egg (edible fraction), excreta I, blood serum I concentration and I apparent retention

TABLE 5 Effects of increasing concentrations of iodine in diet on blood and blood serum indices of laying hens during 32–44 weeks of age[1]

	Iodine concentrations in diets (mg/kg)[2]							*p*-Value[3]		
Parameters	0.74	3.13	5.57	8.11	10.65	12.94	*SEM*	ANOVA	Linear	Quadratic
Blood indices										
WBC (10^9/L)	15.78[ab]	15.83[ab]	16.00[a]	15.93[ab]	15.70[ab]	15.45[b]	0.116	.039	.035	.009
RBC (10^{12}/L)	2.54	2.56	2.69	2.61	2.48	2.47	0.061	.120	.107	.050
HGB (mmol/L)	7.46	7.25	7.39	7.70	7.37	7.32	0.103	.081	.411	.404
HCT (%)	30.83	31.48	30.24	31.41	31.14	31.06	0.413	.341	.951	.864
PLT (g/L)	53.50	52.00	48.00	50.00	46.00	54.00	2.553	.215	.047	.059
Blood serum indices										
T_3 (μg/dl)	9.05[a]	7.00[b]	5.57[c]	4.18[d]	9.57[a]	10.00[a]	0.279	.0001	.0001	.0001
T_4 (μg/dl)	1.32[c]	1.49[b]	1.64[b]	1.82[a]	1.60[b]	1.22[c]	0.034	.0001	.0001	.0001
T_3/T_4	6.85[b]	4.69[c]	3.41[d]	2.31[e]	6.00[b]	8.24[a]	0.202	.0001	.0001	.0001
AST (U/L)	236.13[ab]	218.56[b]	220.03[ab]	222.08[ab]	232.64[ab]	237.63[a]	4.726	.021	.009	.003
ALT (U/L)	3.89[b]	4.54[ab]	4.08[ab]	3.97[ab]	4.14[ab]	4.61[a]	0.180	.041	.640	.405
ALP (U/L)	463.60[ab]	453.29[abc]	411.68[c]	409.01[c]	424.32[bc]	475.40[a]	11.417	.001	.0001	.0001
TG (mmol/L)	9.47[c]	9.68[bc]	9.88[ab]	9.98[a]	9.58[c]	9.54[c]	0.068	.0001	.0001	.0001
CHOL (mmol/L)	3.33[c]	3.86[ab]	3.97[a]	3.72[abc]	3.80[ab]	3.47[bc]	0.101	.001	.0001	.0001
HDL (mmol/L)	1.68	1.56	1.84	1.80	1.76	1.70	0.078	.184	.129	.177
LDL (mmol/L)	1.16	1.10	1.27	1.24	1.21	1.16	0.056	.345	.113	.134
HDL/LDL	1.45[ab]	1.42[b]	1.45[ab]	1.45[ab]	1.45[ab]	1.47[a]	0.011	.041	.544	.277

SEM, Standard error of the means; WBC, white blood cells number; RBC, red blood cells number; HGB, haemoglobin; HCT, haematocrit; PLT, platelets; AST, aspartate aminotransferase; ALT, alanine aminotransferase; ALP, alkaline phosphatase; TG, triglycerides; CHOL, total cholesterol; HDL, high-density lipoproteins; LDL, low-density lipoproteins; T_3, triiodothyronine; T_4, thyroxine.

[a–e]Values within the same row with different superscript letters differ ($p < .05$).

[1]Each value represents the mean of five replicates with three hens per replicate.

[2]Calcium iodate was supplemented at the level of 0.0, 2.5, 5.0, 7.5, 10.0 or 12.5 mg/kg to the diets respectively.

[3]*p* values for linear and quadratic effects of increasing concentrations of iodine in diets.

are presented in Table 6. Iodine concentrations in the eggs were significantly affected by increasing I intake ($p = .0001$). Iodine concentration of 12.94 mg I/kg of diet significantly increased I contents of egg yolk, egg albumen, eggshell and whole egg (edible fraction) from 1.054 to 2.840 μg/g of yolk, 0.014 to 0.180 μg/g of albumen, 36.132 to 39.326 μg/g of eggshell and 0.538 to 1.636 μg/g of whole eggs. Larger proportion of I was concentrated in the eggshell and egg yolk compared to egg albumen.

Iodine concentration in blood serum was significantly increased from 18.39 to 67.12 μg/L; so that hens fed diet containing 12.94 mg I/kg of diet demonstrated higher blood serum I concentration compared with hens fed diet containing 0.74 mg I/kg of diet ($p = .0001$).

4 | DISCUSSION

4.1 | Hens' performance

In agreement with the present study, some researchers reported that I supplementation to layer hens diets had no significant effects on egg production, egg mass production, egg weight, feed intake, FCR, un-normal eggs and body weight changes (Lichovnikova & Zeman, 2004; Opaliński et al., 2012; Yalçin, Kahraman, Yalcin, Yalcin, & Dedeoglu, 2004).

Słupczyńska, Jamroz, Orda, and Wiliczkiewicz (2014) conducted a research on Hy-Line Brown laying hens over 3 and 5 months of periods. Their results demonstrated that the highest laying rate was observed in group receiving 3 mg of I/kg diet given as KIO_3 ($p = .009$). Also, they reported that high level of dietary I (5 mg/kg, as KI or KIO_3) significantly increased the egg mass ($p = .020$), modified the egg weight ($p = .014$), reduced number of damaged eggs ($p < .01$) and improved feed efficiency ($p = .021$). Saki, Farisar, Aliarabi, Zamani, and Abbasinezhad (2012) used Hy-Line W36 layer hens during 10-week investigation. Their result revealed that egg weight was increased by 10 and 15 mg/kg supplemental I from CI source ($p < .05$).

Some researchers suggested that I supplementation to diets may have an effect on the endocrine system, particularly the thyroid gland and also possibility of an alteration in gut microflora: thus can lead to an improvement in nutrients availability (Stolc, Knopp, & Stolcova, 1973). When the amount of I in the feed of layer hens exceeds critical levels (about 2,500 mg I/kg of diet), negative reactions occur that it may lead to a gradual decrease in the rate of production (Lewis, 2004). According to Lichovnikova, Zeman, and Cermakova (2003), the prolonged feeding of excessive amounts of I had adverse effects on egg production and body weight. In their study, it was also observed that I

TABLE 6 Effects of increasing concentrations of iodine in diet on iodine intake, iodine accumulation in egg components, excreta iodine, blood serum iodine and iodine apparent retention in 44-weeks-old laying hens[1]

	Iodine concentrations in diets (mg/kg of diet)[2]							*p*-Value[3]		
Parameters	0.74	3.13	5.57	8.11	10.65	12.94	*SEM*	ANOVA	Linear	Quadratic
Iodine intake (μg day^{-1} hen^{-1})	71.32^{f}	228.64^{e}	393.09^{d}	552.34^{c}	690.51^{b}	863.38^{a}	8.330	.0001	.0001	—
Egg yolk iodine (μg/g yolk)	1.054^{f}	1.436^{e}	2.026^{d}	2.228^{c}	2.638^{b}	2.840^{a}	0.009	.0001	.0001	.0001
Egg albumen iodine (μg/g albumen)	0.014^{f}	0.060^{e}	0.104^{d}	0.120^{c}	0.150^{b}	0.180^{a}	0.003	.0001	.0001	.0029
Eggshell iodine (μg/g shell)	36.132^{f}	37.222^{e}	38.790^{b}	37.554^{d}	38.224^{c}	39.326^{a}	0.009	.0001	.0028	.1756
Whole egg iodine (μg/g egg)	0.538^{f}	1.022^{e}	1.128^{d}	1.338^{c}	1.458^{b}	1.636^{a}	0.009	.0001	.0001	.0001
Excreta iodine (μg/g excreta)	23.09^{f}	166.69^{e}	283.41^{d}	431.10^{c}	607.69^{b}	767.02^{a}	3.851	.0001	.0001	.0029
Blood serum iodine (μg/L)	18.39^{f}	29.19^{e}	37.23^{d}	45.29^{c}	51.16^{b}	67.12^{a}	0.097	.0001	.0001	.0519
Iodine apparent retention (μg/g)	47.69^{d}	60.94 ^{cd}	108.55^{ab}	119.90^{a}	81.37^{bcd}	94.72^{abc}	8.292	.0001	.0003	.0030

SEM, Standard error of the means.
[a–f]Values within the same row with different superscript letters differ ($p < .05$).
[1]Each value represents the mean of five replicates with three hens per replicate.
[2]Calcium iodate was supplemented at the level of 0.0, 2.5, 5.0, 7.5, 10.0 or 12.5 mg/kg to the diets respectively.
[3]*p* values for linear and quadratic effects of increasing concentrations of iodine in diets.

transfer from diet into eggs is much higher than (10%–20%) from feed into meat as shown by dose–response.

4.2 | Egg quality

In agreement with the present study, Christensen and Ort (1990) reported that I supplementation had no significant effects on the egg specific gravity, egg yolk, albumen and eggshell percentages, egg shape and yolk indices, Haugh unit, egg yolk colour and eggshell thickness.

Saki et al. (2012) reported that egg-specific gravity was decreased by 10 mg/kg supplementation of I as CI but they did not find significant difference in shell weight among the treatments. Also they reported that I supplementation to layer diets (5 mg I/kg) significantly improves egg shape, yolk indices and Haugh unit ($p = .014$, $p = .011$ and $p = .049$ respectively). Lichovnikova et al. (2003) found that higher feed I concentration negatively influences yolk, albumen and eggshell weights, in ISA Brown laying hens during a 50-week period ($p < .05$). Słupczyńska et al. (2014) reported that dietary I supplementation (1, 3 and 5 mg/kg as KI or KIO_3) did not significantly affect egg yolk, albumen and eggshell percentages over 3-month experiment but increased albumen ratio after 5 months ($p = .012$) and yolk colour after 3 months of experiment ($p = .003$).

Lichovnikova and Zeman (2004) reported that dietary supplementation of I in range of 3.57 to 6.07 mg I/kg significantly increases the eggshell ratio, eggshell thickness and eggshell strength and also decreases egg yolk index and Haugh unit ($p < .05$). Opaliński et al. (2012) used Hy-Line Brown laying hen during a 12-week period and reported that dietary I supplementation significantly improves the egg yolk colour ($p = .002$). Yalçin et al. (2004) reported that layers fed diet supplemented with 24 mg I/kg had lower Haugh unit than the groups given supplemental I at 0, 3 and 6 mg/kg ($p < .05$) and also they reported that I supplementation up to 5.20 mg/kg did not significantly affect egg quality.

Although the levels of examined Ca and P on the eggshell were diverse, dietary I concentration significantly affected the percentages of eggshell Ca and P. Obtained data are difficult to unequivocally expound due to differences between experimental factors. Levels of Ca and P in blood serum are considered as elements influencing thyroid function and thus may cause disturbance in I metabolism (Kabata-Pendias & Pendias, 1999). Due to the lack of data demonstrating the influence of dietary I concentration on level of Ca and P in eggshell, further studies are necessary.

4.3 | Blood and blood serum indices

All blood and blood serum indices of laying hens in this experiment were within the physiological range that is in accord with findings of Lucas and Jamroz (1961).

There is lack of information concerning the influence of dietary I concentration on blood and blood serum indices of laying hens. Lewis (2004) reported that I supplementation increased HGB levels in blood. Słupczyńska et al. (2014) reported that I supplementation significantly affected the RBC and HGB concentrations in group receiving 5 mg I/kg of diet given as KI ($p = .002$ and $p = .003$ respectively) and did not have significant effects on WBC, HCT and PLT.

Thyroid gland synthesizes and secretes a mixture of T_3 and T_4 hormones, which are important for normal development of the body and metabolism. Perlman, Chaikoff, and Morton (1941) reported that thyroid gland has 100 times ability more than liver and kidneys to retain I.

In contrast with the present study, Słupczyńska et al. (2014) reported that I supplementation (5 mg/kg) in the diet did not significantly affect hepatic enzyme activity. Yue and Kang (1995) reported

that high intakes of I (65 and 130 mg/kg) increased serum AST, ALT and ALP concentrations of laying hens. The results obtained from hepatic enzyme activity indicated a hyper function in liver of hens fed diet containing 12.94 mg/kg I.

Some researchers reported that I supplementation had no significant effect on lipid indices such as TG, CHOL, HDL and LDL (He, Hollwich, & Rambeck, 2002; Saki et al., 2012; Słupczyńska et al., 2014; Yalçin et al., 2004). Krupová, Kratochvil, Kaufmann, Kursa, and Trávníèek (1998) reported that higher I supplementation in the diet increased CHOL level in serum. A regression of data from Perry, Lewis, and Hannagan (1989, 1990) showed that CHOL level in plasma was increased by 0.3 mmol/L for each 100 mg/kg increase in dietary I concentration.

4.4 | Iodine enrichment of egg

Amount of I enrichment in eggs depends on many factors such as basal diet, feed ingredients, I supplementation source, I levels, physiological conditions of birds, environment conditions. Numerous researchers confirmed that increasing I levels in hens diets cause a clear increase in I content of the eggs (Lewis, 2004; Lichovnikova & Zeman, 2004; Lichovnikova et al., 2003; Opaliński et al., 2012; Saki et al., 2012; Słupczyńska et al., 2014; Yalçin et al., 2004).

Cao, Yang, Cheng, Chen, and Chen (1999) reported that laying hens fed diet containing 50 and 100 mg I/kg, plasma I was increased by 1.35 and 2.01 mg/L respectively. Travnicek, Kronpova, and Kursa (2000) fed broilers with diets containing 3.5 and 11.0 mg I/kg and recorded 4.9 and 6.5 mg I/L in plasma respectively. Kaufmann, Wolfram, Delange, and Rambeck (1998) reported high correlation between dietary levels of I and total I content per egg (R^2 = .9153; p < .001). Dobrzański, Górecka, Strzelbicka, Szczypel, and Trziszka (2001) reported that two times higher concentration of I in premix resulted in 52.6% higher I concentration in the eggs after 4-week application compared with the control group.

5 | CONCLUSION

In conclusion, our results demonstrated that dietary supplementation of I up to 12.94 mg/kg of diet (12.5 mg/kg calcium iodate in diet) did not significantly affect productive performance of the hens but could enrich the eggs by I. Blood T_3 and T_4 concentrations were dramatically changed in response to dietary levels of I. Eggshell Ca percentage, blood serum and excreta I and I deposition in whole egg, egg yolk, egg albumen and eggshell were increased as the dietary supplementation of I increased. Highest eggshell strength was observed in dietary I level of 3.13 mg/kg of diet.

In addition, more researches are required to study more comprehensively how thyroid hormones will respond to supplemental iodine and subsequent changes in productive performance and health of the layer hens. Moreover, based on reflection of dietary iodine on egg I concentration, studies should be conducted to evaluate the effects of consumption of enriched eggs on human health.

ACKNOWLEDGEMENTS

Our special appreciation from vice president in research at the Ferdowsi University of Mashhad (Mashhad, Iran) for providing facilities and financial support for this study. We extend our appreciation to Dr. Zerehdaran for his assistance in statistical analysis. We are also grateful to Evonik Degussa for amino acids analysis of feed ingredients.

ORCID

R. Bakhshalinejad http://orcid.org/0000-0002-7735-9156

A. Hassanabadi http://orcid.org/0000-0002-8601-7983

REFERENCES

Ammerman, C., & Miller, S. M. (1972). Biological availability of minor mineral ions: A review. *Journal of Animal Science*, *35*, 681–694. https://doi.org/10.2527/jas1972.353681x

Andersson, M., De Benoist, B., Darnton-Hill, I., & Delange, F. (2007). Iodine deficiency in Europe: a continuing public health problem. WHO/UNICEF Report.

AOAC International (2000). *Official methods of analysis*. Arlington, VA: AOAC International.

Benotti, J., Benotti, N., Pino, S., & Gardyna, H. (1965). Determination of total iodine in urine, stool, diets, and tissue. *Clinical Chemistry*, *11*, 932–936.

Bourre, J. M., & Galea, F. (2006). An important source of omega-3 fatty acids, vitamins D and E, carotenoids, iodine and selenium: A new natural multi-enriched egg. *Journal of Nutrition Health and Aging*, *10*, 371–376.

Cao, S. F., Yang, L., Cheng, M. R., Chen, L. Y., & Chen, K. Q. (1999). Effect of feeding high iron and high-iodine diet to hens on the iron and iodine content in eggs and egg quality. *Journal of Shanghai Agricultural College*, *17*, 248–254.

Card, L. E., & Nesheim, M. C. (1972). *Poultry production* (11th ed., pp. 291–295). Philadelphia, PA: Lea and Febiger.

Carter, T. C. (1975). The hen's egg: Estimation of shell superficial area and egg volume, using measurements of fresh egg weight and shell length and breadth alone or in combination. *British Poultry Science*, *16*, 541–543. https://doi.org/10.1080/00071667508416224

Christensen, V. L., & Ort, J. F. (1990). Influence of diet mediated maternal thyroid alterations on functional properties of turkey eggs. *Poultry Science*, *69*, 1576–1581. https://doi.org/10.3382/ps.0691576

De Benoist, B., McLean, E., Andersson, M., & Rogers, L. (2008). Iodine deficiency in 2007: Global progress since 2003. *Food and Nutrition Bulletin*, *29*, 195–202. https://doi.org/10.1177/156482650802900305

Dobrzański, Z., Górecka, H., Strzelbicka, G., Szczypel, J., & Trziszka, T. (2001). Study on enrichment of hen eggs with selenium and iodine. *Electronic Journal of Polish Agricultural Universities*, *4*(2), #01.

Dunn, J. T. (2003). Iodine should be routinely added to complementary foods. *Journal of Nutrition*, *133*, 3008–3010.

Dyrka, A., Drożdż, R., Naskalski, J. W., Szybiński, Z., & Franek, E. (2011). Assay of iodine in edible salt using Sandell-Kolthoff catalytic method. *Journal of Laboratory Diagnostics*, *47*, 425–429.

Goldhaber, S. B. (2003). Trace element risk assessment: Essentiality vs. toxicity. *Regulatory Toxicology and Pharmacology*, *38*, 232–242. https://doi.org/10.1016/S0273-2300(02)00020-X

Haugh, R. R. (1937). The Haugh unit for measuring egg quality. *U.S. Poultry Magazine*, *43*, 552–573.

He, M. L., Hollwich, W., & Rambeck, W. A. (2002). Supplementation of algae to the diet of pigs: A new possibility to improve the iodine content in

the meat. *Journal of Animal Physiology and Animal Nutrition*, *86*, 97–104. https://doi.org/10.1046/j.1439-0396.2002.00363.x

Hempe, J. M., Laukxen, R. C., & Savage, J. E. (1988). Rapid determination of egg weight and specific gravity using a computerized data collection system. *Poultry Science*, *67*, 902–907. https://doi.org/10.3382/ps.0670902

Hy-Line International (2015). *Hy-Line W36 commercial management guide*. West Des Moines, IA: Hy-Line International.

Kabata-Pendias, A., & Pendias, H. (1999). *Trace elements biogeochemistry* (pp. 398). Warszawa, Poland: PWN.

Kaufmann, S., Wolfram, G., Delange, F., & Rambeck, W. A. (1998). Iodine supplementation of laying hen feed: A supplementary measure to eliminate iodine deficiency in humans. *European Journal of Nutrition*, *37*, 288–293.

Khazan, M., Azizi, F., & Hedayati, M. (2013). A review on iodine determination methods in salt and biological samples. *Scimetr*, *1*, e14092.

Krupová, V., Kratochvil, P., Kaufmann, S., Kursa, J., & Trávníèek, J. (1998). Metabolic effects of iodine addition to laying hens. *Veterinary Medicine*, *43*, 207–212.

Laurberg, P. (2004). Victories and challenges in optimizing iodine intake. *Thyroid*, *14*, 589. https://doi.org/10.1089/1050725041692936

Leeson, S., & Summers, J. D. (2009). *Commercial poultry nutrition*. Nottingham, UK: Nottingham University Press.

Lewis, P. D. (2004). Responses of domestic fowl to excess iodine: A review. *British Journal of Nutrition*, *91*, 29–39. https://doi.org/10.1079/BJN20031017

Lichovnikova, M., & Zeman, L. (2004). The effects of a higher amount of iodine supplement on the efficiency of laying hens fed extruded rapeseed and on eggshell quality. *Czech Journal of Animal Science*, *49*, 199–203.

Lichovnikova, M., Zeman, L., & Cermakova, M. (2003). The long-term effects of using a higher amount of iodine supplement on the efficiency of laying hens. *British Poultry Science*, *44*, 732–734. https://doi.org/10.1080/00071660310001643741

Lucas, A. M., & Jamroz, C. (1961). *Atlas of avian hematology*. Washington, DC: U.S. Department of Agriculture.

Mathe, D., & Chevallier, F. (1976). Effects of the thyroid state on cholesterol metabolism in the rat. *Biochimica et Biophysica Acta*, *441*, 155–164. https://doi.org/10.1016/0005-2760(76)90290-3

McDowell, L. R. (1992). *Iodine, minerals in animal and human nutrition* (pp. 225–245). New York, NY: Academic Press.

Nestel, P. (1993). *Food fortification in developing countries*. Washington, DC: U.S. Agency for International Development.

Opaliński, S., Dolińska, B., Korczyński, M., Chojnacka, K., Dobrzański, Z., & Ryszka, F. (2012). Effect of iodine-enriched yeast supplementation of diet on performance of laying hens, egg traits, and egg iodine content. *Poultry Science*, *91*, 1627–1632. https://doi.org/10.3382/ps.2011-02031

Pekel, A. Y., Demirel, G., Alp, M., Kocabagli, N., & Acar, N. (2012). Influence of different dietary copper sources on eggshell quality and phosphorus retention in laying hens. *The Journal of Applied Poultry Research*, *21*, 460–466. https://doi.org/10.3382/japr.2010-00315

Perlman, I., Chaikoff, I., & Morton, M. (1941). Radioactive iodine as an indicator of the metabolism of iodine I. The turnover of iodine in the tissues of the normal animal, with particular reference to the thyroid. *Journal of Biological Chemistry*, *139*, 433–447.

Perry, G. C., Lewis, P. D., & Hannagan, M. J. (1989). Iodine supplementation from two sources and its effect on egg output. *British Poultry Science*, *30*, 973–974.

Perry, G. C., Lewis, P. D., & Hannagan, M. J. (1990). Responses of the laying hen to dietary iodine supplementation. Proceedings of the 8th European Poultry Conference. Barcelona: Spanish Branch. World's Poult Science Association **1**, 384–387.

Phillips, D. I. W. (1997). Iodine, milk, and the elimination of endemic goitre in Britain: The story and accidental public health triumph. *Journal of Epidemiology and Community Health*, *51*, 391–393. https://doi.org/10.1136/jech.51.4.391

Proudman, J., & Siopes, T. (2002). Relative and absolute photorefractoriness in turkey hens: Profiles of prolactin, thyroxine, and triiodothyronine early in the reproductive cycle. *Poultry Science*, *81*, 1218–1223. https://doi.org/10.1093/ps/81.8.1218

Saki, A. A., Farisar, M. A., Aliarabi, H., Zamani, P., & Abbasinezhad, M. (2012). Iodine-enriched egg production in response to dietary iodine in laying hens. *Journal of Agricultural Technology*, *8*, 1255–1267.

SAS Institute (2009). *SAS statistics user's guide, statistical analysis system, 9.2 version*. Cary, NC: SAS Institute.

Shafer, D., Carey, J., Prochaska, J., & Sams, A. (1998). Dietary methionine intake effects on egg component yield, composition, functionality, and texture profile analysis. *Poultry Science*, *77*, 1056–1062. https://doi.org/10.1093/ps/77.7.1056

Słupczyńska, M., Jamroz, D., Orda, J., & Wiliczkiewicz, A. (2014). Effect of various sources and levels of iodine, as well as the kind of diet, on the performance of young laying hens, iodine accumulation in eggs, egg characteristics, and morphotic and biochemical indices in blood. *Poultry Science*, *93*, 2536–2547.

Soetan, K., Olaiya, C., & Oyewole, O. (2010). The importance of mineral elements for humans, domestic animals and plants: A review. *African Journal of Food Science*, *4*, 200–222.

Stolc, V., Knopp, J., & Stolcova, E. (1973). Effect of varying iodine intake on its concentration in rat tissues during early development. *Neonatology*, *23*, 339–345. https://doi.org/10.1159/000240614

Travnicek, J., Kronpova, V., & Kursa, J. (2000). The effects of excessive iodine intake on activity of leukocytes and the level of plasmatic proteins in laying hens. *Science Agriculture Bohemia*, *4*, 273–284.

Tukey, J. (1991). The philosophy of multiple comparisons. *Statistical Science*, *6*, 100–116. https://doi.org/10.1214/ss/1177011945

Wu, G., Bryant, M. M., Voitle, R. A., & Roland, D. A. (2005). Effect of dietary energy on performance and egg composition of Bovans White and Dekalb White hens during phase I. *Poultry Science*, *84*, 1610–1615. https://doi.org/10.1093/ps/84.10.1610

Yalçin, S., Kahraman, Z., Yalcin, S., Yalcin, S. S., & Dedeoglu, H. E. (2004). Effects of supplementary iodine on the performance and egg traits of laying hens. *British Poultry Science*, *45*, 499–503. https://doi.org/10.1080/00071660412331286208

Yue, W. B., & Kang, J. Q. (1995). Effects of a high-iodine diet on performance, metabolism and egg quality of layers. *Chinese Journal of Veterinary Science*, *26*, 18–22.

How to cite this article: Bakhshalinejad R, Hassanabadi A, Nassiri-Moghaddam H, Zarghi H. The effects of dietary calcium iodate on productive performance, egg quality and iodine accumulation in eggs of laying hens. *J Anim Physiol Anim Nutr*. 2018;00:1–9. https://doi.org/10.1111/jpn.12873