

Laying performance and egg quality of blue-shelled layers as affected by different housing systems

X. L. Wang, J. X. Zheng, Z. H. Ning, L. J. Qu, G. Y. Xu,¹ and N. Yang¹

State Key Laboratory for Agrobiotechnology and Department of Animal Genetics and Breeding, China Agricultural University, Beijing 100193, China

ABSTRACT Blue-shelled eggs are gaining popularity as the consumption demand diversifies in some countries. This study was carried out to investigate the laying performance and egg quality of the blue-shelled egg layers as well as the effects of different housing systems on egg production and quality traits. One thousand pullets from Dongxiang blue-shelled layers were divided into 2 even groups and kept in different housing systems (outdoor vs. cage). Daily laying performance was recorded from 20 to 60 wk of age. External and internal egg quality traits were examined at 26, 34, 42, and 50 wk. Yolk cholesterol concentration and whole egg cholesterol content were measured at 40 wk of age. Average laying rate from 20 to 60 wk for the cage (54.7%) was significantly higher than that of outdoor layers (39.3%). Among all of the egg quality traits, only

eggshell color was affected by housing system. Interaction between housing system and layer age was found in egg weight, eggshell color, eggshell ratio, yolk color, and yolk weight. Meanwhile, cholesterol concentration in yolk was 8.64 ± 0.40 mg/g in the outdoor eggs, which was significantly lower than that of eggs from the cage birds (10.32 ± 0.48 mg/g; $P < 0.05$). Whole egg cholesterol content in the outdoor eggs (125.23 ± 6.32 mg/egg) was also significantly lower than that of eggs from the caged layers (158.01 ± 8.62 mg/egg). The results demonstrated that blue-shelled layers have lower productivity in the outdoor system than in the cage system. Blue-shelled layers have lower egg weight, larger yolk proportion, and lower cholesterol content compared with commercial layers. In a proper marketing system, lower productivity could be balanced by a higher price for the better quality of blue-shelled eggs.

Key words: blue-shelled layer, housing system, productivity, egg quality, cholesterol

2009 Poultry Science 88:1485–1492
doi:10.3382/ps.2008-00417

INTRODUCTION

Eggshell color (**ESC**) is an important external characteristic of eggs. White and brown are 2 main ESC in the poultry industry around the world. In North America, most consumers prefer white eggs, whereas brown eggs are more popular in Asia, Asia Pacific, and Europe (Hooge, 2007). Furthermore, there are other ESC, such as blue. Araucana is a well-known blue-shelled egg layer that has been very well documented (Somes et al., 1977; Peterson et al., 1978). A Chinese indigenous chicken breed named Dongxiang, which originated from Jiangxi Province, also lays blue-shelled eggs and has been used for commercial egg production recently.

Biliverdin, an important pigment in the eggshell of chickens and other avian species, accounts for the blue shell. Zhao et al. (2006) speculated that biliverdin was

most likely synthesized in the shell gland and then deposited onto the eggshell in blue-shelled layers. In addition to its special ESC, the blue-shelled egg is popular in the market for another reason—the absence of trimethylaminuria resulting from the mutation of the flavin-containing monooxygenase 3 gene (Zhang, 2007). Previous studies showed that the Araucana egg has a larger yolk:albumen ratio, lower protein, and higher cholesterol content compared with commercial layers (Somes et al., 1977; Peterson et al., 1978). However, the productivity and egg quality of Dongxiang blue-shelled layers have not been systematically investigated. Because blue-shelled eggs are increasingly popular and blue-shelled layers are widely raised, the first objective of the present study was to measure the productivity and egg quality of the breed.

With the development of the poultry industry, the preference of consumers for chicken eggs is gradually shifting from quantity to quality, and the free-range system has been gaining popularity because of its natural production pattern. Dongxiang layers are historically raised in a free-range system. As the production is

©2009 Poultry Science Association Inc.

Received September 29, 2008.

Accepted March 5, 2009.

¹Corresponding authors: ncpt@cau.edu.cn and nyang@cau.edu.cn

scaled up, they have been caged for economic and management benefits. The main disadvantages of the free-range system are more energy expenditure (AI-Rawi et al., 1976) and more feed consumed due to wastage or changes in nutritional requirements as a result of increased physical activity (Hill, 1986). Additionally, a high incidence of bacterial, parasitic, and viral disease, as well as cannibalism, was found in both litter-based housing systems and free-range systems compared with cage systems (Fossum et al., 2009). However, laying hens in conventional cages are subjected to restricted movement and cannot fulfill most of their natural behaviors (Vits et al., 2005). Cage hens are prevented from dust bathing and roosting because they are deprived of litter and perches. Nest motivation is thwarted by no access to nest sites. Restriction of movement induces bone disease, particularly in legs and wings (Baxter, 1994). In the European Union, all conventional cages will be prohibited from 2012 and replaced with outdoor systems or enriched cages (Horne and Achterbosch, 2008).

Previous studies reported the effect of housing system on laying performance and egg quality (Mench et al., 1986; Carey et al., 1995; Vits et al., 2005; Benyi et al., 2006) and the effect of layer age on egg quality (Rossi and Pompei, 1995; Silversides and Scott, 2001; Suk and Park, 2001). Nevertheless, those studies were performed with commercial layers. The second objective of the study was to investigate the effect of housing system on the laying performance and egg quality for blue-shelled layers. Detailed performance information of this specific breed raised in different housing systems will be very useful for poultry breeders and producers.

MATERIALS AND METHODS

Bird Management

Blue-shelled layers from the Dongxiang conservation zone in Jiangxi Province were used for this study. The birds were vaccinated against Marek's disease, Newcastle disease, avian influenza, infectious bronchitis, infectious laryngotracheitis, and infectious rhinitis after a conventional vaccination program. All of the birds were kept together in brooding and rearing cages from hatching to 14 wk of age, and then 1,000 pullets were divided into 2 groups with 500 individuals each. One group was housed in battery cages, with 3 birds per cage and 520 cm² of floor space per layer, and the other was kept in a large shelter (10 m × 3 m) in access to a pasture of about 300 m². The experiment was carried out from March to December 2007. In both groups, the birds received approximately 10 h of natural light daily at 14 wk of age, and the photoperiod was then increased by 1 h/wk until 16 h of light per day was achieved. No extra heating was provided to both groups, with daily average temperatures ranging from 5 to 30°C. Fifty nest boxes were provided to the outdoor layers. The brooder diet contained 20% CP and 2,850 kcal of ME/kg and

was used before 14 wk of age. Then, a layer diet with 16% CP and 2,550 kcal of ME/kg was provided. Eggs from both systems were collected and counted daily.

Egg Quality Measurements

Freshly laid eggs were collected at 26, 34, 42, and 50 wk. For each examination, 60 eggs were randomly selected from each group to measure the internal and external characteristics. Time interval between the eggs being laid and measured was less than 24 h. The eggs were stored at room temperature before measurement.

The length and breadth of the eggs was measured with the FHK egg shape determinator (Fujihira Industry Co., Tokyo, Japan) and the egg shape index (**ESI**) was calculated (breadth/length × 100). Eggshell color was measured with the EQReflectometer (Fujihira Industry Co.) at 3 places (blunt region, equatorial region, sharp region) with the average calculated. Eggs were tested on the EggShell Force Gauge (Robotmation Co. Ltd., Tokyo, Japan) to determine eggshell strength (**ESS**; Er et al., 2007). Egg weight (**EW**), albumen height (**AH**), Haugh unit (**HU**), and yolk color (**YC**) were measured with the Egg Multi Tester EMT-5200 (Robotmation Co. Ltd.; Asli et al., 2007). Then the yolk and albumen were separated and weighed to determine yolk weight (**YW**) and albumen weight (**AW**). Eggshell was weighed with eggshell membranes giving eggshell weight (**ESW**). Eggshell thickness without inner and outer membranes was measured at the blunt, equatorial, and sharp regions to get the average value (Van Den Brand et al., 2004). The yolk ratio (**YR**, %), the albumen ratio (%), and the eggshell ratio (**ESR**, %) were expressed as $YW/EW \times 100$, $AW/EW \times 100$, and $ESW/EW \times 100$, respectively.

Cholesterol Examination

Twenty eggs for each housing system were collected to measure cholesterol content at 40 wk of age. All of the eggs were examined for yolk cholesterol concentration and whole egg cholesterol content by gas chromatography on an HP6890 gas chromatography system (Hewlett-Packard, Palo Alto, CA) installed with a Chrompack capillary column (HP column, 30 m × 320 μm × 0.25 μm, Varian Inc., Palo Alto, CA). Approximately 0.2 g of yolk was accurately weighed and added to a sample preparation tube with 5 mL of methanolic KOH solution. The tubes were capped tightly and vortexed for 15 s. Treated yolk was then immersed in an 80°C water bath for 15 min with a vortex for 10 s every 5 min. After the water bath, the tube was cooled with tap water and then 1 mL of water and 5 mL of hexane were added. The contents were vortexed vigorously for 1 min and then centrifuged at 2,000 × *g* for 1 min. The upper phase was transferred into the autosampler of a gas chromatograph and analyzed (Fletouris et al., 1998).

Statistical Analysis

All the data were analyzed using the GLM procedure of SAS software (Version 8.0, SAS Institute Inc., Cary, NC). In the model, age and housing system were the main effects and the 2-way interaction between these factors was also considered. Least squares means were used when the main effects were significant.

RESULTS

Laying Performance

Weekly laying rates of blue-shelled layers over the whole laying period in the 2 housing systems are shown in Figure 1. The 2 groups of blue-shelled layers started laying at a similar age. After the first egg, the laying rate increased quickly and reached the peak at about 25 wk of age, with a laying rate of 63 and 55% for the caged and outdoor layers, respectively. Layers in the cages maintained a peak for about 15 wk before decreasing gradually to 40% of laying rate at 60 wk. The outdoor birds, however, had only a short laying peak and then the laying rate decreased constantly down to the lowest production rate of about 15% at 60 wk, apparently affected by the cold weather in winter. For the whole laying period, productivity of the caged layers was higher than that of the outdoor layers. Average laying rate of the outdoor layers (39.3%) was significantly lower than that of the cage layers (54.7%) from 20 to 60 wk. Over 41 wk of laying period, the average egg production per caged and outdoor layers was 157.0 and 112.8, respectively.

Egg Quality

External egg qualities for blue-shelled layers under different housing systems and at various ages are shown in Figure 2. All traits except ESI varied with age of layers. Only ESC was affected by housing system. The EW

increased significantly with layer age in both housing systems. Average EW of the outdoor and cage eggs was 46.11 ± 0.33 g and 46.42 ± 0.34 g, respectively, which was not significantly different ($P > 0.05$). The ESC was significantly affected by housing system ($P < 0.05$), with 52.33 ± 0.37 for the outdoor eggs and 50.49 ± 0.39 for the cage group. Eggshell strength increased with layer age and reached the peak at about 40 wk, with a subsequent decrease, which showed a similar tendency to laying performance. Variation of eggshell thickness was the same as ESS. The ESR varied with age. Neither housing system nor layer age affected ESI.

Internal egg qualities for blue-shelled layers under different housing systems and at various ages are shown in Figure 3. No significant difference was found between the 2 housing system for any of the traits. However, YR varied. The AH of the outdoor eggs decreased with the layer age but was variable for the cage layers. During the laying period, HU decreased in both housing systems. Yolk color in both housing systems fluctuated over the laying period. Yolk weight increased with layer age with a higher rate than EW, which resulted in an increase of YR. It was interesting to note that housing system affected YR and the differential between 2 housing systems increased with layer age. At 50 wk of age, YR was significantly different between the outdoor (30.83%) and cage (30.04%) housing systems ($P < 0.05$). Albumen ratio decreased because of the increase of YR during the laying period and showed no significant difference between the 2 housing systems.

Interactions between layer age and housing system were found for several traits (Table 1). The EW of the outdoor layer increased during the laying period, but for the caged layers, there was almost no change before 34 wk but a more rapid increase of EW in the last laying period than the outdoor layers. The ESC of the outdoor layer was darker than for the caged layers at the first examination (26 wk), but the reverse was found in the following 3 examinations (34, 42, 50 wk). Eggshell ratio of the outdoor layers decreased before 40 wk and then increased but fluctuated for the caged layers. Yolk color in both housing systems was lighter until 34 wk and then became darker. It was darker for the cage system than the outdoor system in the last 3 examinations. The YW of the cage system was higher than the outdoor system at 26 wk, but the outdoor layers had a rapid increase in the YW during the last laying period, which resulted in a heavier yolk (34, 42, and 50 wk).

Cholesterol Content

Results of cholesterol examination for both housing systems are shown in Figure 4. Yolk cholesterol concentrations in eggs from the outdoor and caged layers were 8.64 ± 0.40 and 10.32 ± 0.48 mg/g, respectively, and the concentration of the cage group was significantly higher than the outdoor eggs ($P < 0.05$). Whole egg cholesterol contents for the outdoor and cage groups were 125.23 ± 6.32 mg/egg and 158.01 ± 8.62 mg/

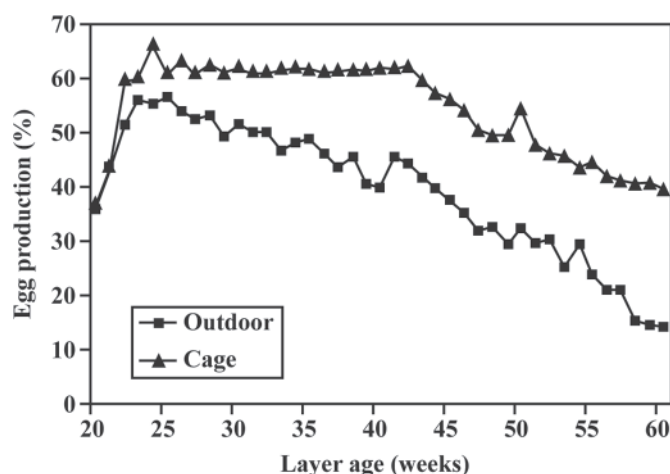


Figure 1. Egg production (%) profile of the outdoor and cage layers from 20 to 60 wk of age. $n = 500$.

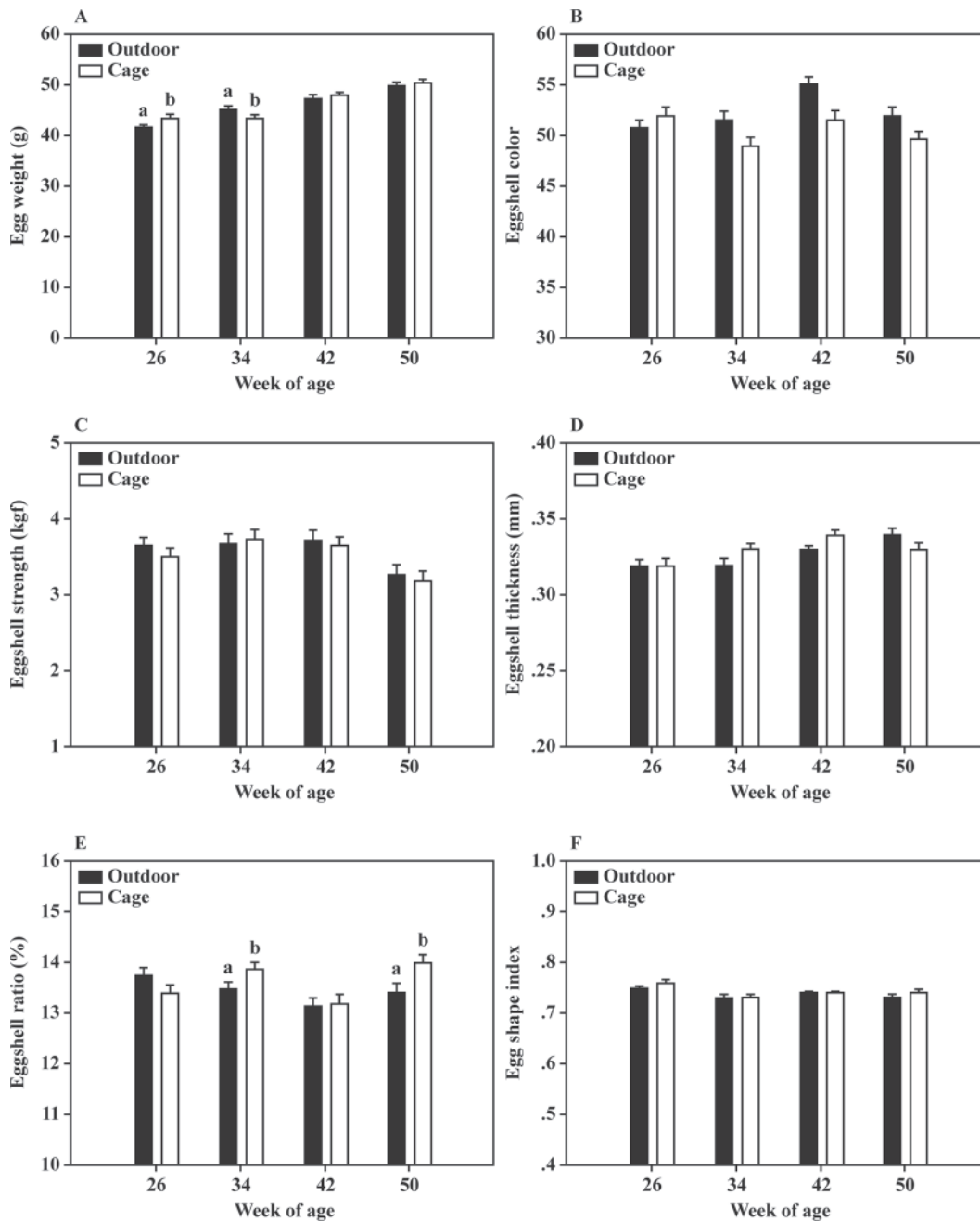


Figure 2. Effects of housing system and layer age on external egg qualities including egg weight (A), eggshell color (B), eggshell strength (C), eggshell thickness (D), eggshell ratio (E), and egg shape index (F). $n = 60$. Values are means. Vertical lines represent the SEM. Values without the same letter are at a significance of $P < 0.05$. Data for the outdoor layers are presented in darkened bars and the cage layers in light bars.

egg, respectively. Eggs laid by the cage layers contained significantly more cholesterol than those laid by the outdoor layers ($P < 0.05$).

DISCUSSION

Laying rate of the blue-shelled layer in both housing systems was significantly lower than commercial layers such as White Leghorn (Tanaka and Hurnik, 1992) in the corresponding housing systems. In the present study, the lower performance of blue-shelled layers in an outdoor system was similar to the result reported for rock partridges reared under different conditions

(Ozbey and Esen, 2007). Compared with the commercial layers, blue-shelled layers have been found to show more movement including running, nesting, and dust bathing, which could require more energy (Al-Rawi et al., 1976) and reduce the productivity of layers. Broodiness might also be a reason for the low productivity.

Blue-shelled layers in both production systems laid smaller eggs, but with a larger yolk proportion, than Hy-Line (Hussein et al., 1993) and ISA Brown layers (Suk and Park, 2001). The AH of blue-shelled layers was lower than ISA Brown layers (Suk and Park, 2001). Mertens et al. (2006) reported that eggs from an aviary system were stronger than cage eggs, and outdoor eggs

were weaker than others. However, Vits et al. (2005) found lower ESS in the high-density housing system. In the present study, ESS increased before 40 wk and decreased thereafter. Eggshell strength was not influenced by housing system. No effect of housing systems was found on ESR, which was similar to the results of O'Sullivan et al. (1991) and Peebles et al. (2000). Only ESC was affected by different housing systems and the color of the outdoor eggs was lighter than that of the cage eggs. Gosler et al. (2005) assumed that protoporphyrin pigments might compensate for reduced ESS, which was caused partly by calcium deficiency. Egg shape index was not affected by housing system in this

study. However, Pavlovski et al. (1981) and Van Den Brand et al. (2004) found longer eggs in cage than in outdoor layers. The different breed used in our study could account for this difference.

Albumen height and HU decreased with layer age in agreement with other studies (Williams, 1992; Silversides and Scott, 2001). Van Den Brand et al. (2004) reported that outdoor layers showed more variable AH with layer age and housing system had no effect on AH and HU. However, Pavlovski et al. (1981) found that AH of outdoor eggs was higher than cage eggs. In the present study, no difference was found in AH between the 2 housing systems. The increased ratio of the yolk

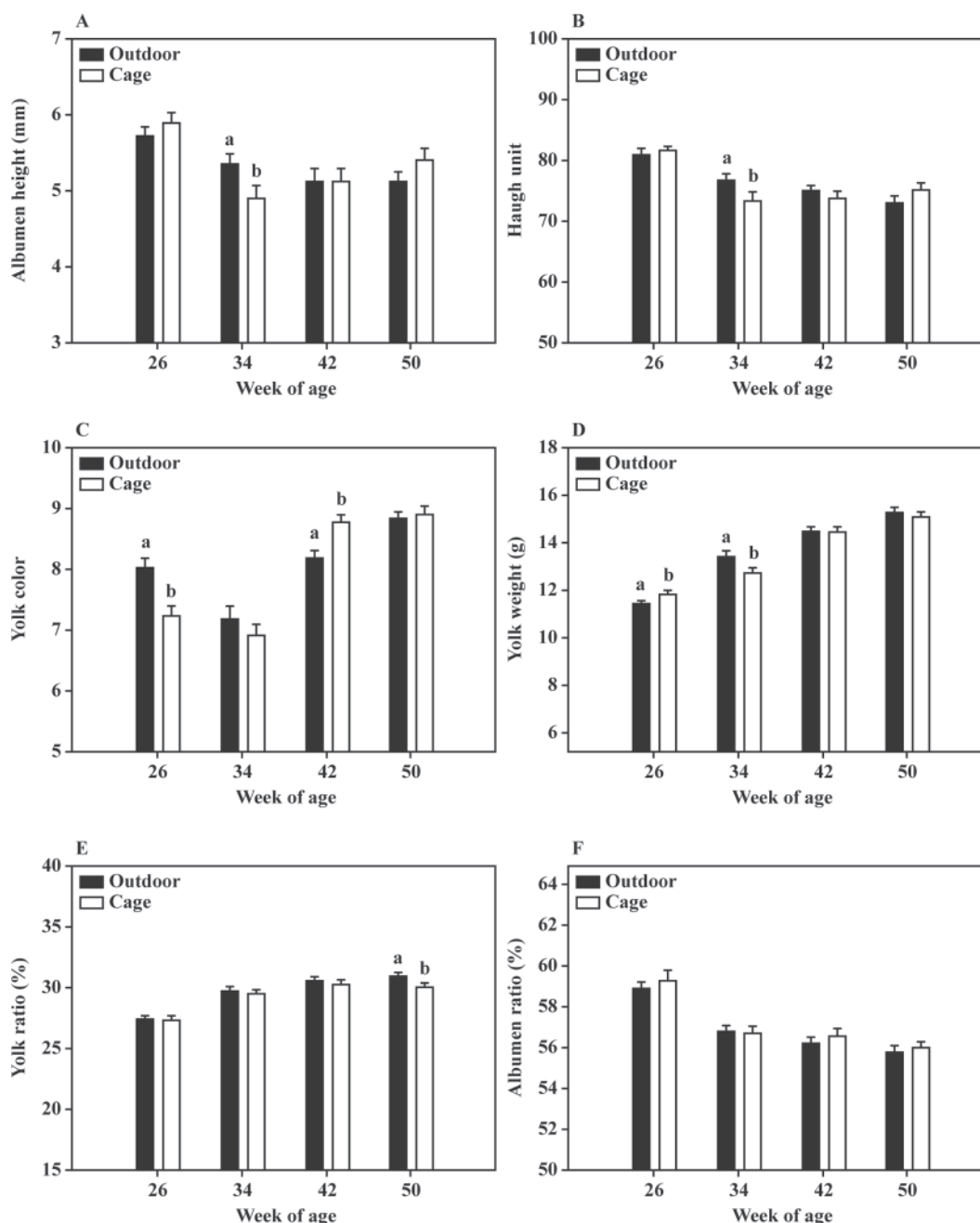


Figure 3. Effects of housing system and layer age on internal egg qualities including albumen height (A), Haugh unit (B), yolk color (C), yolk weight (D), yolk ratio, (E) and albumen ratio (F). $n = 60$. Values are means. Vertical lines represent the SEM. Values without the same letter are at a significance of $P < 0.05$. Data for the outdoor layers are presented in darkened bars and the cage layers in light bars.

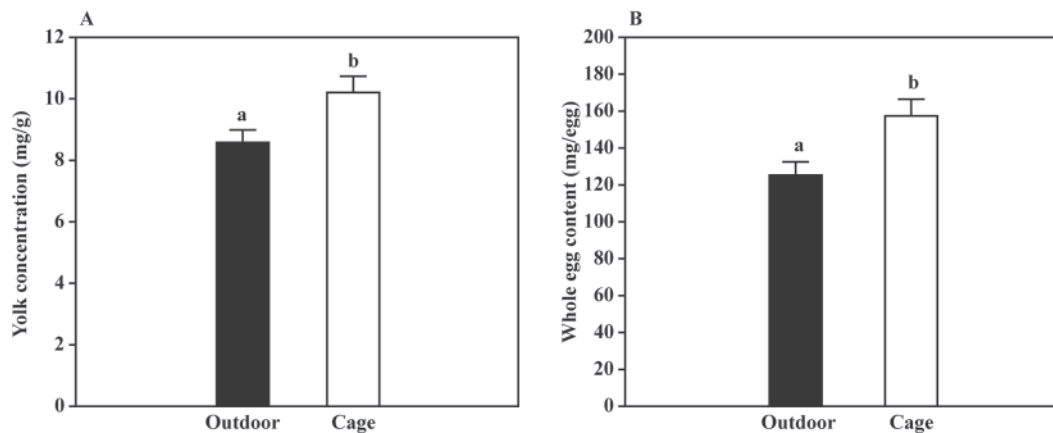


Figure 4. Yolk cholesterol concentration (A) and whole egg cholesterol content (B) in eggs of the outdoor and cage layers. $n = 20$. Values are means. Vertical lines represent the SEM. Values without the same letter are at a significance of $P < 0.05$. Data for the outdoor layers are presented in darkened bars and the cage layers in light bars.

to albumen with the laying period was consistent with the results found by Hussein et al. (1993) and Silver-sides and Scott (2001). Van Den Brand et al. (2004) reported a clear effect of housing system on YC, and a darker yolk in outdoor system was expected. However, we did not find significant differences in YC between the 2 housing systems. It was reported that YC was mainly determined by xanthophylls (Karunajeewa, 1978) because feedstuffs play an important role in the pigment deposition in yolk. In the present study, the same feed was provided to layers for both housing systems, and few additional feedstuffs were available in the pasture to the outdoor layers in the long production period. Therefore, similar feed intakes could be an explanation for the similar YC between the 2 housing systems in our results.

Chicken eggs are well established as an excellent source of almost all essential nutrition for people of all ages (Salma et al., 2007). There is some argument about the relationship of yolk cholesterol and cardio-

vascular disease. Recent studies, however, have found that there is no association between egg consumption and cardiopathies, and egg can be part of an overall heart-healthy diet (Novello et al., 2006; Eckel, 2008). However, many consumers still regard low-cholesterol eggs as a beneficial food for health. Strain was found to have a significant effect on cholesterol content per gram of yolk and per egg (Sheridan et al., 1982), and the average yolk concentration and whole egg content of cholesterol in blue-shelled eggs (9.48 mg/g and 141.62 mg/egg) were significantly lower than those found in conventional eggs (12 mg/g, Ingr et al., 1987, and 213 mg/egg, USDA, 1991). Low-cholesterol content in blue-shelled eggs would attract more consumers, and producers will benefit from that. We also found that the outdoor eggs had significantly lower yolk cholesterol concentration and whole egg content than those of the cage eggs (Figure 4), which could be attributed to the larger YR and more activities of the outdoor birds. It was reported that cholesterol could be metabolized by

Table 1. Effect of housing system and layer age on internal and external egg qualities¹

Traits ²	Outdoor	Cage	Source of variation (P -value)		
			Age	Housing	Age \times housing
EW (g)	46.42 \pm 0.34	46.11 \pm 0.33	<0.0001	0.44	0.006
ESC	52.33 \pm 0.37 ^a	50.49 \pm 0.39 ^b	0.0002	0.0005	0.006
ESS (kgf)	3.56 \pm 0.06	3.51 \pm 0.06	0.0003	0.50	0.91
EST (mm)	0.33 \pm 0.01	0.33 \pm 0.01	<0.0001	0.41	0.23
ESW (g)	6.19 \pm 0.05	6.30 \pm 0.05	<0.0001	0.09	0.06
ESI	73.82 \pm 0.22	74.23 \pm 0.23	<0.0001	0.21	0.53
ESR (%)	13.45 \pm 0.07	13.61 \pm 0.08	0.0018	0.14	0.01
AH (mm)	5.34 \pm 0.07	5.34 \pm 0.08	<0.0001	0.99	0.06
HU	76.75 \pm 0.50	76.15 \pm 0.62	<0.0001	0.42	0.06
YC	8.08 \pm 0.08	7.98 \pm 0.09	<0.0001	0.34	<0.0001
YW (g)	13.68 \pm 0.13	13.57 \pm 0.12	<0.0001	0.38	0.01
YR (%)	29.63 \pm 0.16	29.28 \pm 0.17	<0.0001	0.09	0.56
AR (%)	64.55 \pm 0.82	75.26 \pm 1.18	<0.0001	0.42	0.92

^{a,b}Means in the same row with no common superscript differ significantly at $P < 0.05$.

¹Values are mean \pm SEM. $n = 240$.

²EW = egg weight; ESC = eggshell color; ESS = eggshell strength; EST = eggshell thickness; ESW = eggshell weight; ESI = egg shape index; ESR = eggshell ratio; AH = albumen height; HU = Haugh unit; YC = yolk color; YW = yolk weight; YR = yolk ratio; AR = albumen ratio.

many pathways. Most cholesterol was transported to yolk with very low density lipid, and for the others, some was transported to tissue to construct cells, some converted to cholesterol ramification, and some was digested in the intestines (Hargis, 1988; Griffin, 1990). The metabolism of the outdoor layers might be faster than the cage layers because of the frequent movement. It could be speculated that more movement consumes more energy, and cell construction and digestion used more cholesterol than has been synthesized. Therefore, for the blue-shelled layers, cholesterol deposited to yolk would be less in the outdoor egg than in cages.

In conclusion, productivity of Dongxiang blue-shelled layers was lower than that of conventional layers, especially in the outdoor systems. However, blue-shelled eggs had larger yolk and lower cholesterol content, and their egg quality was generally better than commercial layers. In the outdoor system, blue-shelled layers had a larger yolk proportion and lower cholesterol content than that of the cage birds. The disadvantage of low productivity could be redeemed by a higher price of blue-shelled eggs, which makes their production economically feasible.

ACKNOWLEDGMENTS

The current research was funded in part by the National Scientific Supporting Projects of China (2006BDA01A09, 2008BADB2B06), the National High Technology Development Plan of China (2006AA10A121, 2008AA101009), and the National Basic Research Program of China (2006CB102102).

REFERENCES

- Al-Rawi, B., J. V. Craig, and A. W. Adams. 1976. Agonistic behavior and egg production of caged layers: Genetic strain and group-size effects. *Poult. Sci.* 55:796–807.
- Asli, M. M., S. A. Hosseini, H. Lotfollahian, and F. Shariatmadari. 2007. Effect of probiotics, yeast, vitamin E and vitamin C supplements on performance and immune response of laying hens during high environmental temperature. *Int. J. Poult. Sci.* 6:895–900.
- Baxter, M. R. 1994. The welfare problems of laying hens in battery cages. *Vet. Rec.* 134:614–619.
- Benyi, K., D. Norris, and P. M. Tsatsinyane. 2006. Effects of stocking density and group size on the performance of white and brown Hyline layers in semi-arid conditions. *Trop. Anim. Health Prod.* 38:619–624.
- Carey, J. B., F. L. Kuo, and K. E. Anderson. 1995. Effects of cage population on the productive performance of layers. *Poult. Sci.* 74:633–637.
- Eckel, R. H. 2008. Egg consumption in relation to cardiovascular disease and mortality: The story gets more complex. *Am. J. Clin. Nutr.* 87:799–800.
- Er, D., Z. Wang, J. Cao, and Y. Chen. 2007. Effect of monochromatic light on the egg quality of laying hens. *J. Appl. Poult. Res.* 16:605–612.
- Fletouris, D. J., N. A. Botsoglou, I. E. Psomas, and A. I. Mantis. 1998. Rapid determination of cholesterol in milk and milk products by direct saponification and capillary gas chromatography. *J. Dairy Sci.* 81:2833–2840.
- Fossum, O., D. S. Jansson, P. Engelsen Etterlin, and I. Vagsholm. 2009. Causes of mortality in laying hens in different housing systems in 2001 to 2004. *Acta Vet. Scand.* 51:3.
- Gosler, A. G., J. P. Higham, and S. J. Reynolds. 2005. Why are bird's eggs speckled? *Ecol. Lett.* 8:1105–1113.
- Griffin, H. D. 1990. Egg cholesterol resists change. *Feed Int.* 3:8–14.
- Hargis, P. S. 1988. Modifying egg yolk cholesterol in the domestic fowl – A review. *World's Poult. Sci. J.* 44:17–29.
- Hill, J. A. 1986. Egg production in alternative systems – A review of recent research in the UK. *Res. Dev. Agric.* 3:13–18.
- Hooge, D. M. 2007. *Bacillus subtilis* spores improve brown egg colour. *World Poult.* 23:14–15.
- Horne, V. P. L. M., and T. J. Achterbosch. 2008. Animal welfare in poultry production systems: Impact of EU standards on world trade. *World's Poult. Sci. J.* 64:40–52.
- Hussein, S. M., R. H. Harms, and D. M. Janky. 1993. Research note: Effect of age on the yolk to albumen ratio in chicken eggs. *Poult. Sci.* 72:594–597.
- Ingr, I., J. Simeonova, J. Stavkova, E. Petrovsky, and F. Dostal. 1987. Cholesterol content in market hen eggs. *Nahrung* 31:933–940.
- Karunajeewa, H. 1978. The performance of cross-bred hens given free choice feeding of whole grains and a concentrate mixture and the influence of source of xanthophylls on yolk colour. *Br. Poult. Sci.* 19:699–708.
- Mench, J. A., A. van Tienhoven, J. A. Marsh, C. C. McCormick, D. L. Cunningham, and R. C. Baker. 1986. Effects of cage and floor pen management on behavior, production, and physiological stress responses of laying hens. *Poult. Sci.* 65:1058–1069.
- Mertens, K., F. Bamelis, B. Kemps, B. Kamers, E. Verhoelst, B. De Ketelaere, M. Bain, E. Decuyper, and J. De Baerdemaeker. 2006. Monitoring of eggshell breakage and eggshell strength in different production chains of consumption eggs. *Poult. Sci.* 85:1670–1677.
- Novello, D., P. Franceschini, D. A. Quintiliano, and P. R. Ost. 2006. Egg: Concepts, analyses and controversies in the human health. *Arch. Latinoam. Nutr.* 56:315–320.
- O'Sullivan, N. P., E. A. Dunnington, and P. B. Siegel. 1991. Relationships among age of dam, egg components, embryo lipid transfer, and hatchability of broiler breeder eggs. *Poult. Sci.* 70:2180–2185.
- Ozbey, O., and F. Esen. 2007. The effects of different breeding systems on egg productivity and egg quality characteristics of Rock Partridges. *Poult. Sci.* 86:782–785.
- Pavlovski, Z., B. Masic, and N. Apostolov. 1981. Quality of eggs laid by hens on free range and in cages. Pages 231–235 in *Quality of Eggs, Proceedings of the First European Symposium*. World's Poultry Science Association, Beekbergen, the Netherlands.
- Peebles, E. D., C. D. Zumwalt, S. M. Doyle, P. D. Gerard, M. A. Latour, C. R. Boyle, and T. W. Smith. 2000. Effects of breeder age and dietary fat source and level on broiler hatching egg characteristics. *Poult. Sci.* 79:698–704.
- Peterson, D. W., A. Lilyblade, C. K. Clifford, R. Ernst, A. J. Clifford, and P. Dumn. 1978. Composition of and cholesterol in Araucana and commercial eggs. *J. Am. Diet. Assoc.* 72:45–47.
- Rossi, M., and C. Pompei. 1995. Changes in some egg components and analytical values due to hen age. *Poult. Sci.* 74:152–160.
- Salma, U., A. G. Miah, K. M. Tareq, T. Maki, and H. Tsujii. 2007. Effect of dietary *Rhodobacter capsulatus* on egg-yolk cholesterol and laying hen performance. *Poult. Sci.* 86:714–719.
- Sheridan, A. K., C. S. Humphris, and P. J. Nicholls. 1982. The cholesterol content of eggs produced by Australian egg-laying strains. *Br. Poult. Sci.* 23:569–575.
- Silversides, F. G., and T. A. Scott. 2001. Effect of storage and layer age on quality of eggs from two lines of hens. *Poult. Sci.* 80:1240–1245.
- Somes, R. G. Jr., P. V. Francis, and J. J. Tlustohowicz. 1977. Protein and cholesterol content of Araucana chicken eggs. *Poult. Sci.* 56:1636–1640.
- Suk, Y. O., and C. Park. 2001. Effect of breed and age of hens on the yolk to albumen ratio in two different genetic stocks. *Poult. Sci.* 80:855–858.
- Tanaka, T., and J. F. Hurnik. 1992. Comparison of behavior and performance of laying hens housed in battery cages and an aviary. *Poult. Sci.* 71:235–243.

- USDA. 1991. Nutrient content of foods. Dairy and Egg Products Handbook 8-1. US Department of Agriculture, Washington, DC.
- Van Den Brand, H., H. K. Parmentier, and B. Kemp. 2004. Effects of housing system (outdoor vs cages) and age of laying hens on egg characteristics. *Br. Poult. Sci.* 45:745–752.
- Vits, A., D. Weitzenburger, and O. Distl. 2005. Comparison of different housing systems for laying hens in respect to economic, health and welfare parameters with special regard to organized cages (literature review). *Dtsch. Tierarztl. Wochenschr.* 112:332–342.
- Williams, K. C. 1992. Some factors affecting albumen quality with particular reference to Haugh unit score. *World's Poult. Sci. J.* 48:5–16.
- Zhang, L. C. 2007. Studies on genetic parameters for the candidate genes associated with egg quality traits in chickens. PhD Diss. China Agricultural University, Beijing.
- Zhao, R., G. Y. Xu, Z. Z. Liu, J. Y. Li, and N. Yang. 2006. A study on eggshell pigmentation: Biliverdin in blue-shelled chickens. *Poult. Sci.* 85:546–549.