Effects of Cyclic Heat Stress on Laying Performance, Eggshell Quality, and Calcium and Phosphorus Metabolism in Laying Hens: Postprint

Authors: Diao Huajie, Feng Jinghai, Zhang Minhong, Diao Xinping, Zhou Ying, Li Meng Wang Xuejie

Date: 2017-10-11T00:00:00+00:00

Abstract

This experiment aimed to simulate cyclic high temperature conditions in summer layer houses and investigate the effects of different temperatures on production performance, eggshell quality, and calcium and phosphorus metabolism in laying hens. A total of 288 28-week-old high-producing Hy-Line Brown layers were randomly allocated to four groups: a 21°C thermoneutral group (ad libitum feeding), a 27-30°C cyclic heat stress group (ad libitum feeding), a 29-35°C cyclic heat stress group (ad libitum feeding), and a 21°C pair-fed group (fed according to the feed intake of the 29-35°C cyclic heat stress group on the previous day), with six replicates per group and 12 hens per replicate. The birds were housed in four artificial climate chambers for a 4-week experimental period. The results showed that, compared with the 21°C thermoneutral group, the 27-30°C cyclic heat stress group exhibited significantly decreased average daily feed intake, body weight gain, and average egg weight ($P<0.05$), significantly reduced eggshell strength ($P<0.05$), no significant difference in calcium and phosphorus metabolic rates ($P>0.05$), but significantly decreased calcium and phosphorus absorption ($P<0.05$); except for significantly decreased yolk color ($P<0.05$), other egg quality-related parameters showed no significant differences ($P>0.05$). The 29-35°C cyclic heat stress group showed significantly decreased average daily feed intake, body weight gain, and average egg weight ($P<0.05$), as well as significantly reduced laying rate ($P<0.05$), significantly decreased eggshell thickness and eggshell strength ($P<0.05$), and significantly increased broken egg rate ($P<0.05$). Calcium and phosphorus metabolic rates showed no significant difference ($P>0.05$), while calcium and phosphorus absorption also decreased significantly ($P<0.05$). Both albumen height and yolk color decreased significantly ($P<0.05$). Compared with the 21°C pair-fed group, the 29-35°C cyclic heat stress group showed significantly decreased average egg weight ($P<0.05$), significantly increased feed-to-egg ratio ($P<0.05$), significantly

reduced eggshell strength (P<0.05), no significant differences in calcium and phosphorus metabolic rates and absorption (P>0.05), and no significant differences in egg quality (P>0.05). These results indicate that temperature fluctuations of 27-30°C in summer chicken houses can significantly reduce body weight gain, average egg weight, and eggshell quality in laying hens; while 29-35°C not only significantly reduces body weight gain, laying rate, average egg weight, and eggshell quality, but also significantly affects albumen height and yolk color. The effects of high temperature on laying performance and on albumen height and yolk color may be related to reduced feed intake; high temperature may directly affect eggshell formation, or may affect eggshell quality through reduced calcium and phosphorus absorption.

Full Text

Effect of Cyclic High Temperature on Laying Performance, Egg Shell Quality and Metabolism of Calcium and Phosphorous in Laying Hens

DIAO Huajie[1],[2], FENG Jinghai[1]*, ZHANG Minhong[1], DIAO Xinping[2], ZHOU Ying[1], LI Meng[1],[2], WANG Xuejie[1]

[1]Institute of Animal Sciences, Chinese Academy of Agricultural Sciences, Beijing 100193, China
[2]College of Animal Science and Technology, Northeast Agricultural University, Harbin 150030, China

Abstract

This experiment aimed to simulate the cyclic high temperature conditions in laying hen houses during summer and investigate the effects of different temperature regimens on production performance, egg shell quality, and calcium and phosphorus metabolism in laying hens. A total of 288 high-producing Hy-Line Brown hens aged 28 weeks were randomly allocated to four treatment groups: a 21 °C thermoneutral group (ad libitum feeding), a 27–30 °C cyclic high-temperature group (ad libitum feeding), a 29–35 °C cyclic high-temperature group (ad libitum feeding), and a 21 °C pair-feeding group (fed according to the previous day's intake of the 29–35 °C group). Each group consisted of 6 replicates with 12 hens per replicate, housed in four artificially controlled environmental chambers for a 4-week experimental period. The results showed that compared with the 21 °C thermoneutral group, the 27–30 °C cyclic high-temperature group exhibited significantly reduced average daily feed intake, body weight gain, average egg weight ($P < 0.05$), and egg shell strength ($P < 0.05$). No significant differences were observed in calcium and phosphorus metabolic rates ($P > 0.05$), although calcium and phosphorus absorption decreased significantly ($P < 0.05$). Except for a significant reduction in yolk color ($P < 0.05$), other egg quality parameters showed no significant differences ($P > 0.05$). In the 29–35 °C cyclic high-temperature group, average daily feed intake, body weight gain, and average egg weight decreased significantly ($P < 0.05$), and laying rate also declined significantly ($P < 0.05$). Both egg shell thickness and shell strength were significantly reduced ($P < 0.05$), while broken egg rate increased significantly ($P < 0.05$). Calcium and phosphorus metabolic rates remained unaffected ($P > 0.05$), but their absorption decreased significantly ($P < 0.05$). Albumen height and yolk color were also significantly lower ($P < 0.05$). Compared with the 21 °C pair-feeding group, the 29-35 °C cyclic high-temperature group showed significantly lower average egg weight ($P < 0.05$), significantly higher feed-to-egg ratio ($P < 0.05$), and significantly reduced shell strength ($P < 0.05$), with no significant differences in calcium and phosphorus metabolic rates, absorption, or egg quality ($P > 0.05$). These results indicate that temperatures fluctuating between 27-30 °C in summer hen houses can significantly reduce body weight gain, average egg weight, and egg shell quality. Temperatures of 29-35 °C not only reduce these parameters but also significantly decrease laying rate, albumen height, and yolk color. The effects of high temperature on laying performance, albumen height, and yolk color may be related to reduced feed intake, while high temperature may directly affect shell formation or influence shell quality through decreased calcium and phosphorus absorption.

Keywords: cyclic high temperature; laying hens; laying performance; egg shell quality; calcium and phosphorus metabolic rate

---

Introduction

High ambient temperature during summer adversely affects laying hen production performance and egg shell quality, causing substantial economic losses. Numerous studies have demonstrated that sustained high temperature reduces feed intake, body weight, laying rate, egg weight, and shell quality in laying hens. However, prolonged constant high temperatures rarely occur in practice, and research on cyclic high temperature is relatively limited. Emery et al. reported that cyclic temperatures of 21.1-37.7 °C decreased feed intake by 15.6%, egg weight by 7.4%, and shell thickness by 15.4%. De Andrade et al. similarly found that cyclic temperatures of 26.7-35.6 °C impaired production performance and shell quality.

Egg shell formation is closely associated with calcium and phosphorus metabolism. Mahmoud et al. demonstrated that acute heat stress at 35 °C reduced calcium ion absorption and transport capacity in the duodenum, disrupted acid-base balance, and decreased total blood calcium levels. Odom et al. also reported that acute heat stress significantly reduced blood calcium ion concentrations. Roberts documented that high ambient temperature affects carbonic anhydrase activity related to calcium and phosphorus metabolism. Zhang et al. showed that continuous heat stress at 30.5 °C downregulated expression of the shell gland calcium transport protein CaBP-d28k, thereby affecting shell quality. These studies indicate that both sustained high temperature and higher cyclic temperatures influence laying performance, shell quality, and calcium-phosphorus metabolism.

The optimal temperature for laying hens is generally considered to be 21–23 °C, with some research suggesting peak performance occurs at 21 °C. Currently, most large-scale layer houses in China have installed fan-pad cooling systems, maintaining temperatures generally below 30 °C during summer, while only a few houses rely on natural or mechanical ventilation (where temperatures typically fluctuate between 29-35 °C). However, it remains unclear whether these lower cyclic temperatures affect laying performance and shell quality, leading many producers and researchers to overlook the impact of summer heat. Therefore, this study simulated summer temperature variations in layer houses to investigate the effects of different cyclic high temperatures (27–30 °C and 29–35 °C) on laying performance, shell quality, and calcium-phosphorus metabolism, providing a scientific basis for summer management of laying hens.

Materials and Methods

Experimental Animals and Design

A total of 288 healthy, continuously laying Hy-Line Brown hens aged 28 weeks were selected and randomly divided into four groups: a 21 °C thermoneutral group (ad libitum feeding), a 27–30 °C cyclic high-temperature group (ad libitum feeding), a 29–35 °C cyclic high-temperature group (ad libitum feeding), and a 21 °C pair-feeding group (fed according to the previous day' s intake of the 29–35 °C group). Each group comprised 6 replicates with 12 hens per replicate (housed in 4 layer cages), distributed across four artificially controlled environmental chambers. All groups were maintained on a 16 h light:8 h dark photoperiod with relative humidity set at 60% and free access to water. The 4-week trial was conducted in programmable artificial climate chambers at the State Key Laboratory of Animal Nutrition.

The 21 °C thermoneutral and pair-feeding groups were maintained at a constant temperature of (21 ± 1) °C throughout the experiment, while the two cyclic high-temperature groups were subjected to daily temperature fluctuations of 27–30 °C or 29–35 °C. Chamber temperatures were recorded using micro temperature loggers (DS1922L, USA, accuracy $±$0.5 °C). The daily temperature variations in each chamber are shown in Figure 1 [Figure 1: see original paper].

Experimental Diet and Management

Hens were fed a corn-soybean meal basal diet formulated according to NRC (1994) and the Chinese Feeding Standard of Chickens (NY/T 33—2004), combined with practical production requirements. The composition and nutrient levels of the basal diet are presented in Table 1 . Daily management followed the Hy-Line Brown Management Guide (2014).

Sample Collection and Measurements

Laying Performance: Body weight was measured at the beginning and end of the experiment. Daily feed intake, egg number, broken eggs, and total egg weight were recorded per replicate to calculate body weight gain, average daily feed intake, laying rate, broken egg rate, average egg weight, and feed-to-egg ratio.

Calcium and Phosphorus Metabolism: Total excreta collection method was used to determine calcium and phosphorus metabolic rates and absorption. On day 25, one cage per replicate (3 hens) was selected for 3 consecutive days of accurate feed intake recording. Dietary calcium and phosphorus contents were measured to calculate intake. Excreta were collected daily (with feathers and debris removed), mixed thoroughly, dried, weighed, ground, and sieved through a 40-mesh screen for calcium and phosphorus analysis to calculate excretion.

Metabolic rate (%) = 100 × (intake -excretion) / intake
Absorption (g/d) = intake -excretion

Egg Quality: On day 26, 18 eggs per group (3 per replicate) were randomly collected. A multifunctional egg quality analyzer (EMT5200, Robotmation, Japan) measured shell strength, albumen height, Haugh unit, and yolk color. Shell thickness was measured at the blunt end, equator, and sharp end using an NFN380 instrument (FHK, Japan) and averaged. Yolk cholesterol and triglyceride contents were determined using a Hitachi 7600 automatic biochemical analyzer.

Statistical Analysis

Data from the 21 °C thermoneutral, 27–30 °C, and 29–35 °C groups were analyzed using one-way ANOVA in SAS 9.2, with Duncan’ s multiple comparison test applied when significant differences were detected. Data from the 21 °C pair-feeding and 29–35 °C groups were analyzed using paired t-tests in SAS 9.2. Results are expressed as means ± standard deviation, with $P \leq 0.05$ considered significant and $0.05 < P \leq 0.10$ indicating a trend.

Results

Effects of Cyclic High Temperature on Laying Performance

As shown in Table 2 , cyclic high temperature significantly affected average daily feed intake, laying rate, average egg weight, and body weight gain. Compared with the 21 °C thermoneutral group, the 27–30 °C group showed significantly reduced feed intake, average egg weight, and body weight gain ($P < 0.05$), with no significant differences in laying rate or feed-to-egg ratio ($P > 0.05$). The 29-35 °C group exhibited significant reductions in all these parameters ($P < 0.05$). Compared with the 21 °C pair-feeding group, the 29–35 °C group had significantly lower average egg weight ($P < 0.05$) and higher feed-to-egg ratio ($P < 0.05$).

Effects of Cyclic High Temperature on Egg Shell Quality

Table 3 shows that cyclic high temperature affected egg shell quality. Compared with the 21 °C thermoneutral group, the 27-30 °C group had significantly reduced shell strength ($P < 0.05$), while the 29-35 °C group showed significantly decreased shell thickness and strength ($P < 0.05$) and increased broken egg rate ($P < 0.05$). Compared with the 21 °C pair-feeding group, the 29-35 °C group exhibited significantly lower shell strength ($P < 0.05$), with trends toward reduced shell thickness ($P < 0.10$) and increased broken egg rate ($P = 0.10$).

Effects of Cyclic High Temperature on Calcium and Phosphorus Metabolism

Figure 2 [Figure 2: see original paper] demonstrates that cyclic high temperature did not affect calcium and phosphorus metabolic rates but significantly reduced their absorption. Compared with the 21 °C thermoneutral group, both cyclic temperature groups showed no significant differences in metabolic rates ($P > 0.05$) but had significantly reduced calcium and phosphorus absorption ($P < 0.05$). Compared with the 21 °C pair-feeding group, the 29-35 °C group showed no significant differences in metabolic rates or absorption ($P > 0.05$).

Effects of Cyclic High Temperature on Egg Quality

Table 4 reveals that cyclic high temperature affected egg quality. Compared with the 21 °C thermoneutral group, the 27-30 °C group showed significantly reduced yolk color ($P < 0.05$), while the 29-35 °C group had significantly lower albumen height and yolk color ($P < 0.05$). No significant effects were observed on Haugh unit, cholesterol, or triglyceride contents ($P > 0.05$). However, compared with the 21 °C pair-feeding group, the 29-35 °C group exhibited significantly higher egg cholesterol content ($P < 0.05$).

Discussion

Effects of Cyclic High Temperature on Laying Performance

With the widespread adoption of fan-pad cooling systems, summer temperatures in large-scale layer houses can generally be maintained below 30 °C, leading many producers and researchers to overlook heat effects. This study found that 27-30 °C cyclic high temperature significantly reduced average daily feed intake, body weight gain, and average egg weight, indicating that summer heat can substantially affect laying performance even with cooling systems. In houses using only natural or mechanical ventilation, temperatures may fluctuate between 29-35 °C. Our results show that 29-35 °C cyclic high temperature significantly reduced feed intake, body weight gain, laying rate, and average egg weight. Emery et al. reported that 21.1–37.7 °C cyclic temperatures significantly reduced feed intake and egg weight without affecting laying rate, while De Andrade et al. and Mashaly et al. reported similar findings. The lack of effect on laying rate in previous studies may be attributed to their lower temperature 下限 (21.0–23.9 °C). Our study used a lower limit of 29 °C, which reflects actual summer conditions in layer houses. Additionally, even at the same feed intake level, 29–35 °C cyclic high temperature still significantly reduced average egg weight and increased feed-to-egg ratio, suggesting that reduced feed intake is a major but not sole factor. High temperature may also affect nutrient digestion, absorption, and utilization, or directly impact ovarian follicle development, warranting further investigation.

Effects of Cyclic High Temperature on Egg Shell Quality

High ambient temperature reduces shell thickness and strength, increasing broken egg rates, which represents a major economic loss. This study found that 27–30 °C cyclic high temperature significantly affected shell strength, with broken egg rates showing substantial numerical differences (0.347% vs. 1.517%), demonstrating that summer heat significantly impacts shell quality even with fan-pad systems. Under ad libitum conditions, 29–35 °C cyclic high temperature significantly affected shell thickness, strength, and broken egg rate. Even under pair-feeding conditions, 29–35 °C significantly affected shell strength and showed trends for thickness and broken egg rate, indicating that high temperature may directly affect shell formation. Research has shown that (30.5 ± 0.1) °C significantly downregulates expression of the shell gland calcium transport protein CaBP-d28k and affects carbonic anhydrase activity, suggesting direct effects of high temperature on shell formation that require further investigation.

Effects of Cyclic High Temperature on Calcium and Phosphorus Metabolism

Egg shell formation is closely related to calcium and phosphorus metabolism. This study found that cyclic high temperature did not affect metabolic rates. However, Mahmoud et al. demonstrated in vitro that 35 °C acute heat stress reduced duodenal calcium ion absorption and transport capacity. Odom et al. also found that acute heat stress significantly reduced blood calcium ion levels, indicating that short-term acute heat stress affects intestinal calcium absorption. Wolfenson et al. reported that 35 °C heat stress for 4 days did not affect calcium absorption in turkeys but reduced phosphorus absorption, while after acclimation to 33 °C, 35 °C had no significant effect on either mineral, suggesting adaptation can mitigate heat effects. Our study used cyclic high temperature over a longer duration, which may explain the lack of effect on metabolic rates. Although metabolic rates were unaffected, absorption decreased significantly, primarily due to reduced feed intake. Short-term calcium deficiency can be compensated by mobilizing bone reserves, but long-term negative calcium and phosphorus balance can affect shell quality. Studies have shown that increasing dietary calcium and phosphorus levels during summer heat significantly improves shell strength, thickness, and proportion.

Effects of Cyclic High Temperature on Egg Quality

This study found that 27-30 °C cyclic high temperature reduced yolk color, while 29-35 °C reduced both albumen height and yolk color. Usayran et al. also observed reduced yolk color under 35 °C constant heat, and Bozkurt et al. reported decreased albumen height during summer heat. Our pair-feeding comparison showed no significant effects on albumen height or yolk color, suggesting these reductions may be related to decreased feed intake. Albumen height is affected by thick albumen quantity, while yolk color depends on xanthophyll deposition. Reduced feed intake may lower protein and xanthophyll consumption, decreasing their deposition in eggs. Interestingly, at the same feed intake level, 29-35 °C cyclic high temperature increased egg cholesterol content, suggesting that high temperature may directly promote cholesterol synthesis or transport. The effects of heat on egg quality are closely related to lipid metabolism, with studies showing that high temperature promotes hepatic fat synthesis, accelerates fat transport, and increases abdominal fat deposition in poultry, though the specific effects on cholesterol synthesis and transport require further investigation.

Conclusions

1. Summer house temperatures fluctuating between 27-30 °C significantly reduce average daily feed intake, body weight gain, average egg weight, and shell quality in laying hens. Temperatures of 29-35 °C further significantly reduce laying rate, albumen height, and yolk color.
2. High temperature may directly affect shell formation or influence shell quality through reduced calcium and phosphorus absorption.
3. The effects of high temperature on laying performance, albumen height, and yolk color may be associated with decreased feed intake.

References

[1] ROLAND D A. Research note: egg shell problems: estimates of incidence and economic impact[J]. Poultry Science, 1988, 67(12): 1801-1803.

[2] ST-PIERRE N R, COBANOV B, SCHNITKEY G. Economic losses from heat stress by US livestock industries[J]. Journal of Dairy Science, 2003, 86(S): E52-E77.

[3] ROBERTS J R. Factors affecting egg internal quality and egg shell quality in laying hens[J]. The Journal of Poultry Science, 2004, 41(3): 161-177.

[4] PEGURI A, COON C. Effect of temperature and dietary energy on layer performance[J]. Poultry Science, 1991, 70(1): 126-138.

[5] MARSDEN A, MORRIS T R, CROMARTY A S. Effects of constant environmental temperatures on the performance of laying pullets[J]. British Poultry Science, 1987, 28(3): 361-380.

[6] LILLIE R J, OTA H, WHITEHEAD J A, et al. Effect of environment and dietary energy on caged Leghorn pullet performance[J]. Poultry Science, 1976, 55(4): 1238-1246.

[7] UGURLU N, ACAR B, TOPAK R. Production performance of caged layers under different environmental temperatures[J]. Archiv für Geflügelkunde, 2002, 66(1): 43-47.

[8] PAYNE C G. Practical aspects of environmental temperature for laying hens[J]. World' s Poultry Science Journal, 1966, 22(2): 126-139.

[9] DENG W, DONG X F, TONG J M, et al. The probiotic Bacillus licheniformis ameliorates heat stress-induced impairment of egg production, gut morphology, and intestinal mucosal immunity in laying hens[J]. Poultry Science, 2012, 91(3): 575-582.

[10] DE ANDRADE A N, ROGLER J C, FEATHERSTON W R, et al. Interrelationships between diet and elevated temperatures (cyclic and constant) on egg production and shell quality[J]. Poultry Science, 1977, 56(4): 1178-1188.

[11] ROZENBOIM I, TAKO E, GAL-GARBER O, et al. The effect of heat stress on ovarian function of laying hens[J]. Poultry Science, 2007, 86(8): 1760-1765.

[12] FRANCO-JIMENEZ D J, SCHEIDELER S E, KITTOK R J, et al. Differential effects of heat stress in three strains of laying hens[J]. Journal of Applied Poultry Research, 2007, 16(4): 628-634.

[13] EMERY D A, VOHRA P, ERNST R A, et al. The effect of cyclic and constant ambient temperatures on feed consumption, egg production, egg weight, and shell thickness of hens[J]. Poultry Science, 1984, 63(10): 2027-2035.

[14] MASHALY M M, HENDRICKS III G L, KALAMA M A, et al. Effect of heat stress on production parameters and immune responses of commercial laying hens[J]. Poultry Science, 2004, 83(6): 889-894.

[15] DE ANDRADE A N, ROGLER J C, FEATHERSTON W R. Influence of constant elevated temperature and diet on egg production and shell quality[J]. Poultry Science, 1976, 55(2): 685-693.

[16] BALNAVE D, MUHEEREZA S K. Improving eggshell quality at high temperatures with dietary sodium bicarbonate[J]. Poultry Science, 1997, 76(4): 588-593.

[17] MILLER P C, SUNDE M L. The effects of precise constant and cyclic environments on shell quality and other lay performance factors with Leghorn pullets[J]. Poultry Science, 1975, 54(1): 36–46.

[18] CHEN J, ZHANG S Y. The calcification process of egg shell and calcium metabolism regulation in shell gland[J]. Animal Husbandry and Veterinary Medicine, 2010, 42(11): 93–96.

[19] MAHMOUD K Z, BECK M M, SCHEIDELER S E, et al. Acute high environmental temperature and calcium-estrogen relationship in the hen[J]. Poultry Science, 1996, 75(12): 1555–1562.

[20] ODOM T W, HARRISON P C, BOTTJE W G. Effects of thermal-induced respiratory alkalosis on blood ionized calcium levels in the domestic hen[J]. Poultry Science, 1986, 65(3): 570–573.

[21] ZHANG J C. Effects of environmental factors on production performance and expression of CaBP-d28k and PMCA in shell gland of laying hens[D]. Master' s thesis. Tai' an: Shandong Agricultural University, 2014.

[22] MARSDEN A, MORRIS T R. Quantitative review of the effects of environmental temperature on food intake, egg output and energy balance in laying pullets[J]. British Poultry Science, 1987, 28(4): 693–704.

[23] LIU H L. Effects of different dietary metabolizable energy and protein levels on production performance and egg quality of laying hens under high temperature conditions[D]. Master' s thesis. Wuhan: Huazhong Agricultural University, 2009.

[24] WANG X S, WU W H, QIU Z J, et al. Temperature and humidity distribution patterns in fan-pad cooled layer houses[C]//Proceedings of the Academic Symposium on Ecological Environment and Sustainable Development of Animal Husbandry and the 2012 Annual Conference of the Chinese Association of Animal Science and Veterinary Medicine. Beijing: Chinese Association of Animal Science and Veterinary Medicine, 2012.

[25] ZHANG N Y, LIU H L, ZHANG J F, et al. Investigation and study on environmental conditions of layer houses in central China during summer[J]. Breeding and Feed, 2008(12): 1–5.

[26] YAHAV S, SHINDER D, RAZPAKOVSKI V, et al. Lack of response of laying hens to relative humidity at high ambient temperature[J]. British Poultry Science, 2000, 41(5): 660–663.

[27] USAYRAN N, FARRAN M T, AWADALLAH H H, et al. Effects of added dietary fat and phosphorus on the performance and egg quality of laying hens subjected to a constant high environmental temperature[J]. Poultry Science, 2001, 80(12): 1695–1701.

[28] WOLFENSON D, SKLAN D, GRABER Y, et al. Absorption of protein, fatty acids and minerals in young turkeys under heat and cold stress[J]. British

Poultry Science, 1987, 28(4): 739-746.

[29] YU L, WANG Y Q, ZHOU L G, et al. Study on optimal calcium and phosphorus levels for heat-stressed laying hens[J]. Guangdong Feed, 2008, 17(5): 28-29, 27.

[30] BOZKURT M, KÜÇÜKYILMAZ K, ÇATLI A U, et al. Performance, egg quality, and immune response of laying hens fed diets supplemented with mannan-oligosaccharide or an essential oil mixture under moderate and hot environmental conditions[J]. Poultry Science, 2012, 91(6): 1379-1386.

[31] LI Y. Effects of glucocorticoid and heat stress on hepatic lipid metabolism in laying hens[D]. Master' s thesis. Tai' an: Shandong Agricultural University, 2011.

[32] AKIBA Y, TAKAHASHI K, KIMURA M, et al. The influence of environmental temperature, thyroid status and a synthetic oestrogen on the induction of fatty livers in chicks[J]. British Poultry Science, 1983, 24(1): 71-80.

[33] YOSHIDA N, FUJITA M, NAKAHARA M, et al. Effect of high environmental temperature on egg production, serum lipoproteins and follicle steroid hormones in laying hens[J]. The Journal of Poultry Science, 2011, 48(3): 207-211.

[34] LU Q P. Study on meat quality traits and fat deposition patterns in different broiler genotypes under high temperature environment[D]. Beijing: Chinese Academy of Agricultural Sciences, 2007.

Note: Figure translations are in progress. See original paper for figures.