Effects of Acute Heat Stress on Thermoregulatory Function in Broiler Chickens: Postprint

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Abstract

This study investigated the effects of different acute heat treatments (26 and 31 ℃) on the thermoregulatory function of broiler chickens. Twenty-four 40-day-old male Arbor Acres (AA) broiler chickens were selected and transferred to artificial climate chambers, randomly allocated into three treatments with eight chickens per treatment. The chickens were acclimated for 2 days at 21 ℃ and 60% relative humidity. At 42 days of age, the experimental temperatures were adjusted to 21 (control), 26, and 31 ℃, with 60% relative humidity. The temperature transition was completed within 1 hour. After maintaining the treatment conditions for 2 hours (acute heat treatment), experimental samples were collected and processed within 2 hours. The results showed that, compared with the control treatment: 1) after acute heat treatment at 26 ℃, the core body temperature and skin temperature of broiler chickens increased extremely significantly ($P<0.01$), respiratory rate and blood gas parameters showed no significant changes ($P>0.05$), and blood sodium ion (Na^+) concentration tended to decrease (0.05

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Full Text

Effects of Acute Moderate Temperatures on Thermoregulatory Function in Broiler Chickens

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Abstract

This experiment investigated the effects of different acute moderate temperature treatments (26 and 31°C) on thermoregulatory function in broiler chickens. Twenty-four 40-day-old male Arbor Acres (AA) broiler chickens were transferred to environmental controlled chambers and randomly divided into three treatments (n=8). After a 2-day adaptation period at 21°C and 60% relative humidity, the chamber temperatures were adjusted to 21°C (control), 26°C, or 31°C at 60% relative humidity when the birds reached 42 days of age. The temperature transition was completed within 1 hour, and samples were collected after maintaining the treatment conditions for 2 hours (acute heat treatment), with all collections finished within 2 hours. The results showed that, compared with the control: (1) The 26°C treatment significantly increased core body temperature and skin temperature ($P<0.01$), but had no significant effects on respiratory rate or blood gas indices ($P>0.05$). Blood sodium ion (Na^+) concentration showed a decreasing trend ($0.05<P<0.10$), while triiodothyronine (T_3) concentration decreased significantly ($P<0.05$). (2) The 31°C treatment significantly increased core body temperature, skin temperature, and respiratory rate ($P<0.01$). Blood pH increased significantly ($P<0.01$), while partial pressure of carbon dioxide (PCO_2) and carbonate ion (${CO_3}^{2-}$) concentration decreased significantly ($P<0.01$). Partial pressure of oxygen (PO_2) showed an increasing trend ($0.05<P<0.10$), while Na^+ concentration showed a decreasing trend ($0.05<P<0.10$). Blood potassium ion (K^+) concentration increased significantly ($P<0.01$), while T_3 concentration decreased significantly ($P<0.05$) and corticosterone (CORT) concentration showed an increasing trend ($0.05<P<0.10$). In conclusion, acute moderate temperature treatments (26 and 31°C) affected thermoregulatory function in broiler chickens to varying degrees compared with 21°C.

Keywords: acute moderate temperature; broiler chickens; thermoregulation

Introduction

Heat stress has long been recognized as a serious problem affecting poultry growth and production. When exposed to unfavorable thermal environments, poultry initiate a series of regulatory responses to maintain body temperature homeostasis, involving behavioral changes and various physiological and biochemical reactions related to thermoregulation, including alterations in skin temperature, core body temperature, respiratory rate, acid-base balance, water-salt metabolism, and endocrine function. Understanding these physiological and biochemical regulatory processes is crucial for accurately assessing thermal comfort in broiler chickens and for developing mitigation strategies against heat stress.

However, most current research has focused on high-temperature heat stress environments of 32°C and above, with insufficient attention given to moderate thermal environments (26–31°C). In fact, due to the widespread application of modern technologies in large-scale broiler houses, moderate thermal environments are commonly encountered in practical production and represent a frequent environmental challenge in poultry production. Our research group has previously found that chronic moderate temperature treatments (26 and 31°C for 14 days from 29 to 42 days of age) exerted varying degrees of influence on broiler chickens' glucose and lipid metabolism, avian uncoupling protein (avUCP) mRNA expression, growth performance, immune organ development, intestinal morphology, intestinal mucosal immune function, and time allocation to different resting behaviors. These findings indicate that chronic moderate thermal environments significantly affect multiple physiological and biochemical functions in broiler chickens. However, studies on the effects of acute 31°C moderate heat exposure on physiological and biochemical parameters related to thermoregulation are scarce, and no research on 26°C has been reported. Therefore, this study investigated changes in physiological, blood gas, electrolyte, and endocrine indices in broiler chickens exposed to different acute moderate thermal environments (26 and 31°C) to explore their effects on thermoregulatory function and provide a theoretical basis for evaluating thermal comfort in broiler chickens.

Materials and Methods

1.1 Experimental Animals and Design

Twenty-four 40-day-old male Arbor Acres (AA) broiler chickens from the same hatch, raised under identical management conditions and in good health, were selected (body weight: 2,548$\pm$85 g) and randomly divided into three treatments (n=8 birds each). The birds were transferred to three environmental controlled chambers for a 2-day adaptation period at 21°C and 60% relative humidity. At 42 days of age, the temperature in two chambers was adjusted to 26°C and 31°C, respectively, while one chamber remained at 21°C as the control treatment; all chambers maintained 60% relative humidity. The temperature transition was completed within 1 hour, and samples were collected after maintaining the treatment conditions for 2 hours.

1.2 Feeding Management

The experiment was conducted in environmental controlled chambers at the Changping Experimental Base of the State Key Laboratory of Animal Nutrition, Institute of Animal Sciences, Chinese Academy of Agricultural Sciences. Temperature and humidity were automatically controlled (precision: $\pm$1°C, $\pm 7^{2}$ for 8 birds). The basal diet was formulated according to NRC (1994) standards . Birds had free access to feed and water throughout the experiment.

1.3 Measurement Indicators and Methods

All measurements were collected 3 hours after the start of temperature transition (1 hour for transition + 2 hours of treatment exposure). Measurements were divided among four collection teams: core body temperature (2 persons), respiratory rate (3 persons), skin temperature (3 persons), and blood indices (2 persons). All collections were completed within 2 hours. To avoid interference between measurements, respiratory rate and skin temperature were collected during the first hour after acute treatment, while core body temperature and blood samples were collected during the second hour.

1.3.1 Physiological Indicators Core body temperature was measured using a high-precision digital thermometer JM6200 (resolution: 0.01°C, accuracy: $±$0.05°C). The probe was inserted 5 cm into the rectum, and readings were taken 30 seconds after complete insertion. The entire process from catching the bird to reading the temperature was completed within 1 minute. All 24 birds were measured within 30 minutes.

Respiratory rate was recorded using a Canon EOS 550D camera in video mode, with data counted manually later. Measurements were taken every 10 minutes, recording the number of breaths per minute for each bird across six consecutive measurements. The respiratory rate for each bird was calculated as the average of these six measurements. Each treatment cycle involved 8 birds, with three persons responsible for the three treatments, completing all measurements within 1 hour.

Skin temperature was collected and analyzed using an infrared thermal imager InfReC H2640 (thermal resolution: 0.03°C, accuracy: $±$1%). The lateral side of the head and shank (metatarsus) were photographed vertically from a distance of 0.5 m, with images taken every 3 minutes for 1 hour (20 thermal images per bird). Software analysis recorded the average skin temperature of the facial region and shank area in each image, with the final value for each bird being the average of all 20 measurements. Each treatment cycle involved 8 birds, with three persons responsible for the three treatments, completing all measurements within 1 hour. Infrared imaging is shown in [Figure 1: see original paper].

1.3.2 Blood Gas Indices Cardiac arterial blood was collected using heparin-lithium-anticoagulant-coated needles. One drop of fresh arterial blood was immediately analyzed for blood gas indices using an Abbott i-STAT handheld blood gas analyzer with EC8+ cartridges. All 8 birds in each treatment were sampled.

1.3.3 Blood Electrolyte and Biochemical Indices Blood was collected from the wing vein, centrifuged at 3,000 rpm for 10 minutes, and the supernatant was stored at -80°C for later analysis. Serum sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and chloride (Cl^-) concentrations were measured using kits from Nanjing Jiancheng Bioengineering Institute. Na^+ concentration was determined by turbidimetry using a spectrophotometer and semi-automatic biochemical analyzer, while K^+, Ca^{2+}, and Cl^- concentrations were measured by microplate assay using a Power Wave XS2 microplate reader (USA). Serum triiodothyronine (T_3), thyroxine (T_4), and corticosterone (CORT) kits were also purchased from Nanjing Jiancheng Bioengineering Institute and measured by enzyme-linked immunosorbent assay (ELISA) according to the manufacturer' s instructions using the Power Wave XS2 microplate reader.

1.4 Data Processing

Data were analyzed using SAS 9.1 statistical software. One-way ANOVA was performed for each treatment, followed by Duncan' s multiple comparison tests. Data are presented as "mean ± standard deviation." $P<0.05$ was considered significant, and $P<0.01$ was considered highly significant.

Results

2.1 Effects of Acute Moderate Temperature on Physiological Indices

As shown in , 2-hour acute moderate temperature treatment had highly significant effects on core body temperature, respiratory rate, and skin temperature ($P<0.01$). Specifically, the 31°C treatment resulted in significantly higher core body temperature, respiratory rate, and skin temperature compared with both 21°C and 26°C treatments ($P<0.01$). The 26°C treatment significantly increased core body temperature and skin temperature compared with the 21°C treatment ($P<0.01$), but showed no significant difference in respiratory rate ($P>0.05$).

2.2 Effects of Acute Moderate Temperature on Blood Gas Indices

As shown in , 2-hour acute moderate temperature treatment had highly significant effects on blood pH, partial pressure of carbon dioxide (PCO_2), and carbonate ion (CO_3^{2-}) concentration ($P<0.01$), but no significant effect on partial pressure of oxygen (PO_2) ($P>0.05$). The 31°C treatment resulted in significantly higher blood pH compared with the 21°C treatment ($P<0.01$) and significantly higher than the 26°C treatment ($P<0.05$). The 31°C treatment also significantly decreased blood PCO_2 and CO_3^{2-} concentration compared with both 21°C and 26°C treatments ($P<0.01$). No significant differences in blood gas indices were observed between the 26°C and 21°C treatments ($P>0.05$).

2.3 Effects of Acute Moderate Temperature on Water-Salt Metabolism

As shown in , 2-hour acute moderate temperature treatment had a highly significant effect on blood K^+ concentration ($P<0.01$) but no significant effects on blood Na^+, Ca^{2+}, or Cl^- concentrations ($P>0.05$). Both 26°C and 31°C treatments showed a decreasing trend in blood Na^+ concentration compared with the 21°C treatment ($0.05<P<0.10$). The 31°C treatment significantly increased blood K^+ concentration compared with both 21°C and 26°C treatments ($P<0.01$).

2.4 Effects of Acute Moderate Temperature on Endocrine Indices

As shown in , 2-hour acute moderate temperature treatment had a significant effect on blood T_3 concentration ($P<0.05$) but no significant effects on T_4 or CORT concentrations ($P>0.05$). Both 26°C and 31°C treatments significantly decreased blood T_3 concentration compared with the 21°C treatment ($P<0.05$). The 31°C treatment showed an increasing trend in blood CORT concentration compared with the 21°C treatment ($0.05<P<0.10$).

Discussion

3.1 Effects of Acute Moderate Temperature on Broiler Physiological Function

Core body temperature, skin temperature, and respiratory rate accurately reflect the thermoregulatory status and thermal comfort of broiler chickens. Acute heat stress elevates poultry core body temperature, as reported by Lacey et al., who found that acute exposure to 31, 34, and 37°C for 5 hours increased broiler core body temperature in a temperature-dependent manner. Our study similarly demonstrated that 2-hour exposure to 26°C and 31°C significantly increased core body temperature compared with 21°C, with greater temperature increases at higher ambient temperatures.

High ambient temperatures also increase avian skin temperature. Cangar et al. found that environmental temperature changes significantly elevated skin temperature in various body regions including comb, wattles, face, neck, wings, abdomen, shanks, webs, and toes. De Souza et al. noted that bare skin areas were more sensitive to temperature changes than feathered areas, showing greater temperature fluctuations. In this study, we employed infrared thermal imaging technology to investigate the effects of moderate temperature on skin temperature, benefiting from its high precision, non-contact, non-invasive nature, and lack of disturbance to the subjects, ensuring objective and reliable data. Our results showed that 2-hour exposure to 26°C and 31°C significantly increased facial and shank skin temperatures compared with 21°C, with greater increases at higher ambient temperatures.

Birds lack sweat glands and rely on accelerated respiration for evaporative cooling when ambient temperature exceeds the critical temperature. Raup et al. reported that acute exposure to 35°C increased chicken respiratory rate from 19 to 188 breaths/min. Zhou et al. found that 3-hour exposure to 30°C gradually increased broiler respiratory rate from 30 to 200 breaths/min. In our study, 2-hour exposure to 31°C increased respiratory rate by 86 breaths/min, while 26°C had no significant effect. It is generally believed that when ambient temperature exceeds the thermoneutral zone, broilers first increase skin temperature, then accelerate respiration for heat dissipation, and only when temperature is too high for thermoregulatory compensation does core body temperature increase.

However, our study found that 26°C significantly increased core body temperature without affecting respiratory rate. This may be related to intermittent panting in birds, where broilers do not maintain continuously high respiratory rates in hot environments but rather pant intermittently to balance heat dissipation with acid-base homeostasis. Although 26°C significantly increased core body temperature compared with 21°C, the increase was only 0.4°C, which falls within the normal diurnal rhythm variation of core body temperature. This modest increase may represent an adaptive adjustment to minimize the adverse effects of evaporative cooling while maintaining thermal balance, rather than a failure of thermoregulation.

3.2 Effects of Acute Moderate Temperature on Blood Gas Indices

During acute heat stress, broiler respiratory rates can exceed 100 breaths/min, defined as thermal panting. Excessive respiratory rate increases gas exchange between the body and environment, affecting blood acid-base balance and gas indices. Arad et al. found that hyperventilation in hot environments reduced blood CO_2 and induced mild respiratory alkalosis. Smith et al. reported that acute heat stress increased blood pH in poultry. Li et al. observed that 37°C exposure for 1 day increased respiratory rate by 60 breaths/min and altered blood gas indices. Our results showed that 2-hour exposure to 26°C and 31°C significantly affected blood gas indices: 31°C significantly increased blood pH and decreased PCO_2 and $CO_3{}^{2-}$ concentration compared with 21°C, while PO_2 showed an increasing trend. No significant differences were observed between 26°C and 21°C treatments. These findings align with the effects on respiratory rate, where 31°C significantly increased respiratory rate while 26°C did not. Thus, acute moderate temperature exposure placed broilers in a thermally uncomfortable state, prompting them to increase respiratory rate for evaporative cooling, which in turn enhanced gas exchange and affected blood acid-base balance and gas indices.

3.3 Effects of Acute Moderate Temperature on Water-Salt Metabolism

In hot environments, broilers increase urine output to dissipate excess heat, representing an important thermoregulatory pathway. Van Kampen et al. reported that high temperatures increased urine output in chickens. Belay et al. noted that increased urine output also caused substantial loss of mineral ions. Fu et al. reported that high temperatures decreased blood Na^+ concentration while increasing K^+ and Ca^{2+} concentrations. Similar findings of decreased blood Na^+ concentration under heat stress were reported by Liu et al. and Deyhim et al. Our study found that compared with 21°C, acute 31°C exposure for 2 hours caused a decreasing trend in blood Na^+ concentration and a significant increase in K^+ concentration, with no significant effects on Ca^{2+} or Cl^- concentrations. The 26°C treatment showed no significant differences in ion concentrations compared with 21°C. The elevated physiological indices under moderate temperature indicated that broilers were in a thermally uncomfortable state requiring thermoregulatory responses. Under acute heat treatment, rapid and substantial urine output could release significant heat while causing mineral ion loss and decreasing blood ion concentrations. The differential effects of 26°C and 31°C on blood ion concentrations suggest that 26°C acute exposure caused milder heat stress that did not require extensive excretion for thermoregulation.

3.4 Effects of Acute Moderate Temperature on Endocrine Function

The thyroid and adrenal glands are important endocrine organs that regulate metabolic heat production. Thyroid hormones T_3 and T_4 and corticosterone (CORT) are key hormones involved in energy metabolism and thermoregulation, serving as common stress indicators. Moderate thermal environments induce thermal discomfort, stimulating hormone secretion to regulate heat production and maintain thermal balance. Yang et al. reported that high ambient temperature significantly decreased blood T_3 concentration. Tao et al. found that blood T_3 and T_4 concentrations gradually decreased with increasing temperature and exposure duration. Jiang et al. reported that chronic 32°C exposure initially decreased T_3 concentration significantly, which later increased above control levels, while T_4 concentration increased initially then recovered, and CORT concentration remained significantly higher than control. Liu et al. reported that 33°C high temperature significantly increased plasma CORT concentration. Our study found that 2-hour acute moderate temperature exposure significantly decreased blood T_3 concentration and showed an increasing trend in CORT concentration, with no significant effect on T_4 concentration. These results indicate that acute moderate temperatures of 26°C and 31°C represented thermal discomfort for broilers, eliciting varying degrees of thermoregulatory responses that altered glucocorticoid and adrenal hormone levels. These changes reduced energy metabolism and heat production to maintain thermal balance while mobilizing energy reserves to cope with external stress and enhance stress resistance.

Conclusion

1. Acute exposure to 26°C significantly increased core body temperature and skin temperature, significantly decreased blood T_3 concentration, and showed a decreasing trend in blood Na^+ concentration in broiler chickens.

2. Acute exposure to 31°C significantly increased core body temperature, skin temperature, and respiratory rate; significantly increased blood pH and K^+ concentration; significantly decreased PCO_2 and ${CO_3}^{2-}$ concentration; significantly decreased blood T_3 concentration; and showed increasing trends in PO_2 and CORT concentration along with a decreasing trend in Na^+ concentration.

3. Compared with 21°C, acute moderate temperature treatments (26 and 31°C) affected thermoregulatory function in broiler chickens to varying degrees.

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