Effects of ambient temperature on the growth performance, fat deposition, and intestinal morphology of geese from 28 to 49 days of age

Z. L. Liu,*1 Y. Chen,*1 J. J. Xue,* X. F. Huang,* Z. P. Chen,* Q. G. Wang,*1 and C. Wang*1,2

*Poultry Science Institute, Chongqing Academy of Animal Sciences, Rongchang, Chongqing 402460, China; and
1Scientific Observation and Experiment Station of Livestock Equipment Engineering in Southwest, Ministry of Agriculture, Chongqing 402460, China

ABSTRACT This study was conducted to investigate the effects of ambient temperature on the growth performance, fat deposition, and intestinal morphology of geese from 28 to 49 d of age. A total of 120 twenty-eight-day-old geese were randomly allotted to 5 environmentally controlled chambers with ambient temperatures set at 18, 21, 24, 27, and 30°C from 28 to 49 d of age, respectively. The feed intake, 49 d body weight, and weight gain decreased linearly or quadratically ($P < 0.05$) as ambient temperature increased and declined to a minimum when the temperature increased to 30°C. The feed/gain showed a linear or quadratic ($P < 0.05$) increasing response to increasing temperature. According to broken-line regression, the upper critical levels of ambient temperature from 28 to 49 d of age for weight gain and feed intake were 25.19 and 23.97°C, respectively. As ambient temperature increased from 18 to 30°C, the abdominal fat weight, abdominal fat rate, and subcutaneous fat thickness decreased linearly ($P < 0.05$) and were accompanied by linearly increasing liver fat content ($P < 0.05$), but the ambient temperature had no effect on intermuscular fat width or breast muscle fat content ($P > 0.05$). There were no differences in jejunal, ileal, or cecal morphology for geese raised at 18, 21, 24, 27, and 30°C ($P > 0.05$). The duodenal villus height showed a linear decreasing response to increasing ambient temperature, but the ambient temperature had no effect on crypt depth, villus width, muscularis thickness, or villus height/crypt depth of the duodenum ($P > 0.05$). These results indicate that high ambient temperature decreased growth performance and fat deposition and impaired duodenal morphology of geese. Under our experimental conditions, we recommend that the upper critical ambient temperature for geese from 28 to 49 d of age be 25.19°C.

Key words: goose, ambient temperature, growth performance, fat deposition, intestinal morphology

INTRODUCTION Moderate ambient temperature in the house is a prerequisite for commercial poultry to maintain health and performance. In modern large-scale and highly efficient poultry production systems, high or low ambient temperatures can cause major economic losses to the poultry industry by reducing the growth rate and increasing mortality (Balog et al., 2003; Niu et al., 2009; Olfati et al., 2018). Birds subjected to high ambient temperature are characterized by altered physiology, behavior and performance (Wasti et al., 2020). Specifically, high ambient temperature reduced feed intake and body weight gain, increased feed conversion ratio (FCR) in broilers (Quinteiro-Filho et al., 2010; He et al., 2018; Ma et al. 2018) and ducks (Sun et al., 2019; Xie et al., 2019). Similarly, high ambient temperature decreased body antioxidant capacity (Sahin et al., 2017), nutrient absorption and intestinal immunity (Yi et al., 2016), impaired intestinal morphology (Song et al., 2018), deteriorated carcass quality in broilers (Zhang et al., 2012), and reduced breast and leg meat yield of growing White Pekin ducks (Sun et al., 2019; Xie et al., 2019). Low ambient temperatures remain a threat to growth performance and intestinal health, particularly for young poultry. Low ambient temperatures increased feed intake but decreased the production potential of broiler chickens (Olfati et al., 2018; Zhou et al., 2021), laying hens (Sahin et al., 2001) and Japanese quails (Shit et al., 2012). Furthermore, cold stress caused by low ambient temperature can increase energy requirements, disrupt physiological homeostasis, alter immune response and...
behavior, lead to ascites syndrome and higher mortality, increase production costs in broiler chickens, and impair egg production and feed efficiency in laying hens (Deeb et al., 2002; Balog et al., 2003). Therefore, it is vital to keep the ambient temperature stable and appropriate during the life cycle of poultry in consideration of the economic benefits and poultry welfare. The optimal performance temperature for growing broilers has been reported to range from 18 to 24°C (Saleh et al., 2021). In Pekin ducks, the upper critical ambient temperatures for starter ducks and growing ducks were 31.3 and 27°C, respectively (Sun et al., 2019; Xie et al., 2019).

With the progression of animal husbandry in China, commercial goose production has changed from conventional free-range and open water outdoor production to confinement in housing; hence, control of ambient temperature has become more critical than before. In geese production, a multiple-phase feeding strategy is generally adopted when considering the long grow-out period for geese. Undoubtedly, there are different moderate ambient temperatures between starter (d 1–28) and grower (d 29–70) geese, but the moderate temperature requirements for each rearing stage have not been reported. Therefore, the objective of the current experiment was to investigate the effects of ambient temperature on growth performance, fat deposition, and intestinal morphology, evaluating the moderate ambient temperature of geese from 28 to 49 d of age.

MATERIALS AND METHODS

Experimental Design, Birds, and Management

This study was approved by the Animal Care and Welfare Committee of the Chongqing Academy of Animal Science (CAAS), China. All geese used in this study were obtained from the CAAS goose-breeding center.

A total of 120 twenty-eight-day-old White Sichuan geese (Anser cygnoides) were randomly allotted to 5 environmentally controlled chambers (9 m²/chamber) with ambient temperatures set at 18, 21, 24, 27, and 30°C, respectively. The environmentally controlled chambers were made of an air conditioner, ventilation devices, heater, humidifier, and dehumidifier. Geese remained in the chambers until 49 d. The relative humidity of all chambers was set at 60% during this period. In each chamber, 24 birds were divided randomly into 6 raised wire-floor pens of 4 birds each. All birds had similar initial body weights at the start of the experiment. The indoor temperature and humidity were monitored by a thermometer at 3 h intervals. The recorded average temperatures of the treatments were 18.39, 20.87, 23.82, 26.52, and 30.33°C, respectively. The lighting program was 16 L: 8 D and the geese had ad libitum access to water and feed during the entire experimental period. The distribution of lighting and ventilation was the same in all chambers and pen locations within the individual chambers were similar for all chambers to avoid the influence of pen location on ventilation. Water was provided by drip-nipple water supply lines, and the birds were fed commercial corn-soybean-based diets in pellet form formulated according to breed requirements containing 11.75 MJ metabolizable energy/kg and 160 g crude protein/kg.

Data Collection and Measurements

Growth Performance At 21:00 on d 48, geese were fasted (water available) for 12 h. The BW of each pen was recorded at 09:00 on d 49, and the weight of the remaining feed of each pen was recorded. The weight gain, feed intake, and FCR were calculated for the 21-d period (n = 6).

Fat Deposition At 49 d of age, after a 12 h fast, 1 goose was selected from each pen according to the average body weight of corresponding pen and exsanguinated by cutting the jugular vein. After bleeding for 5 min, geese were scalded in water at 60°C for 4 min prior to defeathering, manual evisceration, and sample collection. The abdominal fat (comprising fat tissues surrounding the proventriculus and gizzard lying against the inside abdominal wall and around the cloaca), breast meat (including pectoralis major and pectoralis minor muscles), and liver were removed manually from carcasses. The abdominal fat rate was calculated based on abdominal fat weight/body weight %. The liver and breast meat were collected and stored at −20°C for fat analysis. The fat (ether extract) content was determined according to the Association of Official Analytical Chemists (AOAC, 2000). Meanwhile, a vernier caliper was used to measure the subcutaneous fat thickness after skin incision at the dorsal midline in front of the caudal vertebrae and intermuscular fat width at the end of the sternum xiphoid. The value used was the average of the 3 measurements.

Intestinal Morphology At 49 d, a total of 30 birds (6 birds per treatment) after a 12 h fast were selected according to the average body weight of the corresponding pen, slaughtered, carcass opened, and the entire gastrointestinal tract excised. The intestine was divided into 4 segments: the duodenum (from the pyloric junction to the most distal point of insertion of the duodenal mesentery), jejunum (from the most distal point of insertion of the duodenal mesentery to the junction with Meckel's diverticulum), ileum (from the junction with Meckel's diverticulum to the ileocecal junction), and cecum. Approximately 1 cm sections from the middle portion of the duodenum, jejunum, ileum, and cecum tissues were separated from all connective tissue and fat, washed with 0.1 M phosphate buffered saline to remove the gut contents and immediately fixed in 10% formaldehyde phosphate buffer. Then, the sections were dehydrated in a graded ethanol (xylene) series and embedded in paraffin, and 5-μm-thick cross-sections were sliced and mounted on slides. The slides were then stained with hematoxylin-eosin and viewed under a digital camera microscope (BA400 Digital, McAudi Industrial Sciences).
Group Co., Ltd., Xiamen, China). The Motic Advanced 3.2 digital image analysis system was used to measure villus height (from the villus tip to the villus-crypt junction), crypt depth (from the villus-crypt junction to the base of the crypt), villus width (width of the villus at one-half of the villus height), muscularis thickness (from the submucosa to the external layer of the intestine), and mucosal thickness. The villus height, crypt depth, and villus width of 10 well-oriented villi and 10 muscularis thicknesses were measured in each slide of the duodenum, jejunum and ileum, and the ratio of villus height to crypt depth was calculated by dividing the villus height by the crypt depth. Meanwhile, 10 muscularis thicknesses and 10 mucosal thicknesses were measured in each slide of the cecum.

Statistical Analysis

The data obtained from the experiment were analyzed by one-way ANOVA with SAS software (SAS Institute Inc., 2003), with pens used as the experimental units for analysis. When temperature treatment was significant, means were compared using Duncan’s multiple comparison procedure of SAS software (SAS Institute Inc., 2003). Linear and quadratic polynomial contrasts were performed to determine the effects of ambient temperature on performance and a probability level of $P < 0.05$ was considered to be statistically significant.

The upper critical temperature was estimated by broken-line regression (Huynh et al., 2005). The upper critical temperature was designated as the inflection point temperature above which the goose response started to change. The broken-line model was provided as follows: $y = l + u (x - r)$, where $y$ = goose response (feed intake or weight gain), $x$ = ambient temperature ($°C$), $r$ = breakpoint between two lines (defined as the optimal ambient temperature), $u$ = the slope of the curve, and $l$ = maximum or minimum response if $x < r$ and $y = l + u (x - r)$ if $x \geq r$.

RESULTS AND DISCUSSION

Growth Performance

The effects of ambient temperature on the growth performance of geese are presented in Table 1. The feed intake, 49-day-old body weight, and weight gain decreased linearly or quadratically ($P < 0.05$) as ambient temperature increased and declined to a minimum when the temperature increased to $30°C$. The FCR showed a linear or quadratic ($P < 0.05$) increasing response to increasing temperature. Our results were partly supported by previous studies in broilers (Sohail et al., 2012; Zhang et al., 2015; Yi et al., 2016; Sahin et al., 2017; He et al., 2018; Ma et al., 2018; Song et al., 2018) and ducks (Sun et al., 2019; Xie et al., 2019), which showed that high ambient temperature depresses feed intake, body weight, and weight gain. When ambient temperature is higher than the thermoneutral temperature, it can lead to higher body temperature and, thus, heat burden. Then, birds decrease their feed intake to diminish metabolic heat production, resulting in lower body weight gain (Song et al., 2013, 2018; Sahin et al., 2017). Therefore, high temperature impairs growth performance in geese via a reduction in feed intake. The present study showed that higher ambient temperature increased FCR, which is consistent with other previous findings (Sohail et al., 2012; Sahin et al., 2017; Ma et al., 2018). It is possible that the decreased body weight gain caused by high temperature is greater than the reduction in feed intake, leading to an increase in FCR.

There were no differences in feed intake or weight gain between geese fed at the ambient temperatures of 18, 21, and $24°C (P > 0.05$, Table 1), which indicated that there existed a temperature plateau and that the upper critical temperature for goose growth and the growth response was reduced when the temperature went beyond the upper critical temperature. According to broken-line regression, the upper critical level of ambient temperatures from 28 to 49 d of age for weight gain and feed intake were 25.19 and 23.97°C, respectively (Figures 1 and 2). Recently, Sun et al. (2019) reported that the upper critical ambient temperatures of male White Pekin ducks during the growing period for body weight, weight gain, and FCR were 27.4, 27.4, and 26°C, respectively. It is clear that different physiological and productive parameters of poultry have different critical temperatures. Under our experimental conditions, it appears that lower temperatures improved body weight, weight gain, and FCR. Therefore, we recommend that the upper critical temperature of geese from 28 to 49 d of age should be kept at 25.19°C. Although our study had no mortality in growing geese, we caution that low ambient temperatures could lead to ascites.

Fat Deposition

The effects of ambient temperature on fat deposition of geese are presented in Table 2. As ambient

Table 1. Effects of ambient temperature on the growth performance of geese from 28 to 49 d of age.1

| Item                  | Ambient temperature | SEM | $P$-value | Linear | Quadratic |
|-----------------------|---------------------|-----|-----------|--------|-----------|
| Body weight (g/bird)  | 18°C                | 3,367.94 $^a$ | <0.001 | <0.001 | 0.006     |
|                       | 21°C                | 3,205.83 $^{ab}$ | <0.001 | <0.001 | 0.005     |
|                       | 24°C                | 3,256.11 $^{ab}$ | <0.001 | <0.001 | 0.003     |
|                       | 27°C                | 3,109.22 $^b$ | <0.001 | <0.001 | 0.006     |
|                       | 30°C                | 2674.17 $^c$ | <0.001 | <0.001 | 0.045     |
| Feed intake (g/bird/day) | 18°C                | 86.39 $^a$ | <0.001 | <0.001 | 0.005     |
|                       | 21°C                | 78.93 $^{ab}$ | <0.001 | <0.001 | 0.003     |
|                       | 24°C                | 80.86 $^{ab}$ | <0.001 | <0.001 | 0.006     |
|                       | 27°C                | 75.89 $^c$ | <0.001 | <0.001 | 0.005     |
|                       | 30°C                | 54.28 $^c$ | <0.001 | <0.001 | 0.003     |
| Feed conversion ratio (feed/gain) | 18°C                | 2.89 $^a$ | 0.07 | 0.014 | 0.042     |
|                       | 21°C                | 2.98 $^a$ | 0.07 | 0.014 | 0.042     |
|                       | 24°C                | 2.89 $^b$ | 0.07 | 0.014 | 0.042     |
|                       | 27°C                | 2.85 $^b$ | 0.07 | 0.014 | 0.042     |

1Results are means with $n = 6$ per treatment.

$^{a,b,c}$Means with different superscripts within the same row differ significantly ($P < 0.05$).
temperature increased from 18 to 30°C, the abdominal fat weight, abdominal fat rate, and subcutaneous fat thickness decreased linearly \((P < 0.05)\) and were accompanied by linearly increasing liver fat content \((P < 0.05)\). However, there were no differences in intermuscular fat width or breast muscle fat content between geese fed at the ambient temperatures of 18, 21, 24, 27, and 30°C \((P > 0.05)\). An early fast growth rate in poultry is accompanied by increased body fat deposition. In this study, high ambient temperature may decrease feed intake and weight gain, resulting in depression of growth performance, and decreasing abdominal fat deposition in geese. Lu et al. (2007) showed that Arbor Acres broiler chickens exposed to an ambient temperature of 34°C had slightly decreased abdominal fat deposition and significantly decreased subcutaneous fat and intermuscular fat deposition compared to those exposed to an ambient temperature of 21°C. On the other hand, Sahin et al. (2017) observed that a high ambient temperature \((34 \pm 2°C \text{ for } 8 \text{ h/d and } 22 \pm 2°C \text{ for } 16 \text{ h/d})\) caused depressions in feed intake and weight gain as well as elevations in feed conversion and abdominal fat rate. He et al. (2019) also found a higher abdominal fat content in ducks under high temperature \((32°C \text{ for } 8 \text{ h per day})\). In fact, recent studies have demonstrated that high ambient temperature is associated with depression of meat chemical composition and quality in broilers (Dai et al., 2012; Imik et al., 2012). Zhang et al. (2012) showed that constant high temperature \((\text{temperature was } 34°C)\) increased fat content and decreased protein

---

**Figure 1.** Weight gain response to ambient temperature of geese.

**Figure 2.** Feed intake response to ambient temperature of geese.
content in the breast muscle of broilers. Similarly, Lu et al. (2017) reported that high temperature (32°C) significantly increased the fat content of breast muscles in broilers. However, our results showed that ambient temperature had no effect on breast muscle fat content but linearly increased liver fat content in geese from 28 to 49 d of age. The differences reported above could be related to the age of the bird, the mode of high temperature, the region used to measure fat deposition, and breed.

### Intestinal Morphology

The effects of ambient temperature on intestinal morphology of geese are presented in Table 3. The duodenal villus height showed a linear decreasing ($P < 0.05$) response to increasing ambient temperature, but the ambient temperature had no effect on crypt depth, villus width, muscularis thickness, or ratio of villus height to crypt depth in the duodenum ($P > 0.05$). There were no differences in the villus height, crypt depth, villus width, muscularis thickness or ratio of villus height to crypt depth of the jejunum and ileum for geese fed at ambient temperatures of 18, 21, 24, 27, and 30°C ($P > 0.05$). No differences were observed in the mucosal thickness or muscularis thickness of the cecum ($P > 0.05$). Therefore, ambient temperature did not affect jejunal, ileal, or cecal morphology, but high ambient temperature induced deterioration of duodenal morphology, showing decreased duodenal villus height. These results were partly in agreement with Marchini et al. (2011), who found that high temperature decreased crypt depth, mucous area, and villus height of the duodenum but did not influence the area of the mucosa, crypt depth or villus height in the jejunum or ileum. In addition, some studies also observed that high temperature had a negative impact on intestinal morphology in poultry, resulting in a decrease in nutrient utilization. The vast majority of these studies consistently reported that high temperature decreased villus height and increased crypt depth, leading to a lower ratio of villus height to crypt depth in broilers (Song et al., 2014, 2018; Santos et al., 2015; He et al., 2018; Wu et al., 2018), laying hens (Deng et al., 2012), and ducks (He et al., 2019). It is likely that high ambient temperature reduces the feed utilization.

### Table 2. Effects of ambient temperature on fat deposition of geese from 28 to 49 d of age.

| Item                              | 18°C  | 21°C  | 24°C  | 27°C  | 30°C  | SEM  | $P$-value | Linear | Quadratic |
|-----------------------------------|-------|-------|-------|-------|-------|------|-----------|--------|-----------|
| Abdominal fat weight (g)          | 120.68| 97.83 | 102.90| 89.92 | 80.50 | 7.42 | 0.014     | 0.002 | 0.709     |
| Abdominal fat rate (%)            | 3.38  | 2.99  | 3.18  | 2.96  | 2.74  | 0.20 | 0.235     | 0.047 | 0.911     |
| Subcutaneous fat thickness (mm)   | 2.81  | 2.16  | 2.44  | 1.84  | 1.75  | 0.22 | 0.013     | 0.002 | 0.765     |
| Intermuscular fat width (mm)      | 12.81 | 12.23 | 12.07 | 11.68 | 11.90 | 0.69 | 0.820     | 0.290 | 0.597     |
| Breast muscle fat content (%)     | 7.02  | 7.14  | 7.31  | 7.10  | 6.97  | 0.30 | 0.938     | 0.883 | 0.437     |
| Liver fat content (%)             | 10.57 | 11.77 | 11.82 | 12.96 | 14.58 | 1.07 | 0.129     | 0.012 | 0.634     |

1Results are means with $n = 6$ per treatment.  
$^{a,b,c}$Means with different superscripts within the same row differ significantly ($P < 0.05$).

### Table 3. Effects of ambient temperature on intestinal morphology of geese at 49 d of age.

| Item                              | 18°C  | 21°C  | 24°C  | 27°C  | 30°C  | SEM  | $P$-value | Linear | Quadratic |
|-----------------------------------|-------|-------|-------|-------|-------|------|-----------|--------|-----------|
| Duodenum Villus height            | 841.91| 954.51| 819.64| 745.65| 647.39| 58.26| 0.014     | 0.003 | 0.110     |
| Crypt depth                       | 276.42| 275.48| 257.92| 265.10| 264.43| 18.67| 0.820     | 0.283 | 0.680     |
| Villus width                      | 87.24 | 81.86 | 81.56 | 80.06 | 79.23 | 5.07 | 0.324     | 0.082 | 0.248     |
| Muscularis thickness              | 348.42| 358.28| 356.93| 375.58| 346.22| 28.48| 0.014     | 0.003 | 0.110     |
| Villus height /crypt depth        | 3.22  | 3.52  | 3.20  | 3.00  | 2.46  | 0.36 | 0.324     | 0.082 | 0.248     |
| Jejunum Villus height             | 857.91| 860.74| 854.57| 899.70| 764.41| 72.66| 0.756     | 0.525 | 0.416     |
| Crypt depth                       | 212.27| 222.39| 206.62| 186.20| 187.30| 16.54| 0.469     | 0.112 | 0.717     |
| Villus width                      | 160.65| 151.69| 138.59| 156.09| 140.24| 10.61| 0.514     | 0.288 | 0.675     |
| Muscularis thickness              | 375.06| 384.89| 357.55| 343.09| 352.35| 33.09| 0.412     | 0.925 | 0.822     |
| Villus height /crypt depth        | 4.47  | 4.03  | 4.30  | 4.88  | 4.06  | 0.53 | 0.787     | 0.991 | 0.822     |
| Ileum Villus height               | 828.65| 935.69| 741.69| 845.50| 812.75| 52.63| 0.169     | 0.470 | 0.927     |
| Crypt depth                       | 192.47| 183.84| 237.11| 178.91| 184.31| 16.08| 0.098     | 0.679 | 0.178     |
| Villus width                      | 154.96| 132.74| 129.18| 150.28| 153.48| 12.50| 0.450     | 0.716 | 0.119     |
| Muscularis thickness              | 337.87| 307.25| 343.10| 325.04| 330.60| 24.77| 0.868     | 0.967 | 0.845     |
| Villus height /crypt depth        | 4.31  | 4.71  | 3.42  | 4.75  | 4.48  | 0.38 | 0.125     | 0.761 | 0.378     |
| Cecum Mucosal thickness           | 337.82| 376.20| 359.97| 326.27| 379.18| 30.20| 0.068     | 0.734 | 0.919     |
| Muscularis thickness              | 182.68| 216.80| 213.88| 222.69| 198.56| 21.51| 0.688     | 0.585 | 0.205     |

1Results are means with $n = 6$ per treatment.  
$^{a,b,c}$Means with different superscripts within the same row differ significantly ($P < 0.05$).
intake of birds, thus greatly reducing the amount of energy delivered to the gastrointestinal tract cells, resulting in delayed intestinal mucosal development.

CONCLUSIONS AND APPLICATIONS

In conclusion, high ambient temperature depresses growth performance, diminishes abdominal fat deposition and subcutaneous fat thickness, and damages the duodenal morphology of geese. Under our experimental conditions, we recommend that the upper critical ambient temperature for geese from 28 to 49 d of age be 25.19°C.

ACKNOWLEDGMENTS

This work was sponsored by the earmarked fund for General Project of Chongqing Natural Science Foundation (cstc2019jcyj-msxmX0077), China Agriculture Research System of MOF and MARA (CARS-42-22), the Key R & D Project in Agriculture and Animal Husbandry of Rongchang (cstc2020ngzx0007), and Cooperative Extension Project of Major Agricultural Technology in Chongqing (21315).

DISCLOSURES

There are no conflicts of interest with any individual or organization.

REFERENCES

AOAC. 2000. Official Methods of Analysis. 17th ed. Assoc. Anal. Chem., Arlington, VA.
Balog, J. M., B. D. Kidd, W. E. Huff, G. R. Huff, N. C. Rath, and N. B. Anthony. 2003. Effect of cold stress on broilers selected for resistance or susceptibility to ascites syndrome. Poult. Sci. 82:1883–1887.
Dai, S., F. F. Gao, X. L. Xu, W. H. Zhang, S. X. Song, and G. H. Zhou. 2012. Effects of dietary glutamine and gamma-aminobutyric acid on meat colour, pH, composition, and water-holding characteristic in broilers under cyclic heat stress. Br. Poult. Sci. 53:471–481.
Deeb, N., A. Shlosberg, and A. Cahner. 2002. Genotype-by-environment interaction with broiler genotypes differing in growth rate. 4. Association between responses to heat stress and to cold-induced ascites. Poult. Sci. 81:1454–1462.
Deng, W., X. F. Dong, J. M. Tong, and Q. Zhang. 2012. The probiotic Bacillus licheniformis ameliorates heat stress-induced impairment of egg production, gut morphology, and intestinal mucosal immunity in laying hens. Poult. Sci. 91:575–582.
He, J., Y. He, D. Pan, J. Cao, Y. Sun, and X. Zeng. 2019. Associations of gut microbiota with heat stress-induced changes of growth, fat deposition, intestinal morphology, and antioxidant capacity in ducks. Front. Microbiol. 10:903.
He, X., Z. Lu, B. Ma, L. Zhang, J. Li, Y. Jiang, G. Zhou, and F. Gao. 2018. Effects of chronic heat exposure on growth performance, intestinal epithelial histology, appetite-related hormones and genes expression in broilers. J. Sci. Food. Agric. 98:4471–4478.
Huynh, T. T. T., A. J. A. Aarnink, M. W. A. Verstegen, W. J. J. Gerrits, M. J. W. Heetkamp, B. Kemp, and T. T. Canh. 2005. Effects of increasing temperatures on physiological changes in pigs at different relative humidities. J. Anim. Sci. 83:1385–1396.
Imik, H., M. A. Atasever, S. Urgar, H. Ozu, R. Gumus, and M. Atasever. 2012. Meat quality of heat stressed exposed broilers and effect of protein and vitamin E. Br. Poult. Sci. 53:689–698.
Lu, Q., J. Wen, and H. Zhang. 2007. Effect of chronic heat exposure on fat deposition and meat quality in two genetic types of chicken. Poult. Sci. 86:1059–1064.
Lu, Z., X. He, B. Ma, L. Zhang, J. Li, Y. Jiang, G. Zhou, and F. Gao. 2017. Chronic heat stress impairs the quality of breast-muscle meat in broilers by affecting redox status and energy-substance metabolism. J. Agric. Food Chem. 65:11251–11259.
Ma, R., X. He, Z. Lu, L. Zhang, J. Li, Y. Jiang, G. Zhou, and F. Gao. 2018. Chronic heat stress affects muscle hypertrophy, muscle protein synthesis and uptake of amino acid in broilers via insulin like growth factor-mammalian target of rapamycin signal pathway. Poult. Sci. 97:4150–4158.
Marchini, C. F. P., P. L. Silva, M. R. B. M. Nascimento, and M. E. Beletti. 2011. Body weight, intestinal morphology and cell proliferation of broiler chickens submitted to cyclic heat stress. Int. J. Poult. Sci. 10:455–460.
Ni, Z., F. Z. Liu, Q. L. Yan, and W. C. Li. 2009. Effects of different levels of vitamin E on growth performance and immune responses of broilers under heat stress. Poult. Sci. 88:2101–2107.
Ollati, A., A. Mojtahedizadeh, T. Saleghi, M. Akbari, and F. Martinez-Pastor. 2018. Comparison of growth performance and immune responses of broiler chicks reared under heat stress, cold stress and thermoneutral conditions. Span. J. Agric. Res. 16: e605.
Quintero-Filho, W. M., A. Ribeiro, V. Ferraz-de-Paula, M. L. Pinheiro, M. Sall, L. R. M. Sí, A. J. P. Ferreira, and J. Palermo-Neto. 2010. Heat stress impairs performance parameters, induces intestinal injury and decreases macrophage activity in broiler chickens. Poult. Sci. 89:1905–1914.
Sahin, K., O. Küçük, and N. Sahin. 2001. Effects of dietary chromium picolinate supplementation on performance and plasma concentrations of insulin and corticosterone in laying hens under low ambient temperature. J. Anim. Physiol. Anim. Nutr. 85:142–147.
Sahin, N. A., C. O. Havirli, M. Tuzcu, F. Akdemir, J. R. Komorowski, and K. Sahin. 2017. Effects of the supplemental chromium oxid form on performance and oxidative stress in broilers exposed to heat stress. Poult. Sci. 96:4317–4324.
Saleh, A. A., K. A. Amber, M. M. Soliman, M. Y. Soliman, W. A. Morsy, M. Shukry, and M. H. Alzawqari. 2021. Effect of low protein diets with amino acids supplementation on growth performance, carcass traits, blood parameters and muscle amino acids profile in broiler chickens under high ambient temperature. Agriculture 11:1–12.
Santos, R. R, A. Awati, P. J. Roubos-van den Hil, M. G. G. Tersteeg-Zijderveld, P. A. Koolmees, and J. Fink-Gremmels. 2015. Quantitative histo-morphometric analysis of heat-stress-related damage in the small intestines of broiler chickens. Avian Pathol. 44:19–22.
SAS Institute Inc. 2003. SAS User’s Guide: Statistics. Version 9.0. SAS Institute Inc., Cary, NC.
Shit, N., R. P. Singh, K. V. H. Sastry, R. Agarwal, R. Singh, N. K. Pandey, and J. Mohan. 2012. Effect of dietary L-ascorbic acid (L-AA) on production performance, egg quality traits and fertility in egg quail (Coturnix japonica) at low ambient temperature. Asian-Aust. J. Anim. Sci. 25:1009–1014.
Sohail, M. U., M. E. Hume, J. A. Byrd, D. J. Nisbet, A. Ijaz, A. Sohail, M. Z. Shabbir, and H. Rehman. 2012. Effect of supplementation of probiotic mannan-oligosaccharides and probiotic mixture on growth performance of broilers subjected to chronic heat stress. Poult. Sci. 91:2235–2240.
Song, J., L. F. Jiao, K. Xiao, Z. S. Luan, C. H. Hu, B. Shi, and X. A. Zhan. 2013. Cello-oligosaccharide ameliorates heat stress-induced impairment of intestinal microflora, morphology and barrier integrity in broiler chickens. Food Sci. Technol. 185:173–181.
Song, J., K. Xiao, Y. L. Ke, L. F. Jiao, C. H. Hu, Q. Y. Diao, B. Shi, and X. T. Zou. 2014. Effect of probiotic mixture on intestinal microflora, morphology, and barrier integrity of broilers subjected to heat stress. Poult. Sci. 93:581–588.
Song, Z. H., K. Cheng, X. C. Zheng, H. Ahmad, L. L. Zhang, and T. Wang. 2018. Effects of dietary supplementation with enzymatically treated Artemisia annua on growth performance, intestinal
morphology, digestive enzyme activities, immunity, and antioxidant capacity of heat-stressed broilers. Poult. Sci. 97:430–437.

Sun, P. X., Z. J. Shen, J. Tang, W. Huang, S. S. Hou, and M. Xie. 2019. Effects of ambient temperature on growth performance and carcass traits of male growing White Pekin ducks. Br. Poult. Sci. 60:513–516.

Wasti, S., N. Sah, and B. Mishra. 2020. Impact of heat stress on poultry health and performance, and potential mitigation strategies. Anim. 10:1266.

Wu, Q. J., N. Liu, X. H. Wu, G. Y. Wang, and L. Lin. 2018. Glutamine alleviates heat stress induced impairment of intestinal morphology, intestinal inflammatory response, and barrier integrity in broilers. Poult. Sci. 97:2675–2683.

Xie, M., P. X. Sun, Y. L. Feng, Y. Jiang, J. Tang, W. Huang, Q. Zhang, and S. S. Hou. 2019. Effects of post-hatch brooding temperature on performance of starter and growing Pekin ducks. Poult. Sci. 98:3647–3651.

Yi, D., Y. Q. Hou, L. L. Tan, M. Liao, J. Q. Xie, L. Wang, B. Y. Ding, Y. Yang, and J. S. Gong. 2016. N-acetylcysteine improves the growth performance and intestinal function in the heat-stressed broilers. Anim. Feed Sci. Technol. 220:83–92.

Zhang, J. F., Z. P. Hu, C. H. Lu, M. X. Yang, L. L. Zhang, and T. Wang. 2015. Dietary curcumin supplementation protects against heat-stress-impaired growth performance of broilers possibly through a mitochondrial pathway. J. Anim. Sci. 93:1656–1665.

Zhang, Z. Y., G. Q. Jia, J. J. Zuo, Y. Zhang, J. Lei, L. Ren, and D. Y. Feng. 2012. Effects of constant and cyclic heat stress on muscle metabolism and meat quality of broiler breast fillet and thigh meat. Poult. Sci. 91:2931–2937.

Zhou, H. J., L. L. Kong, L. X. Zhu, X. Y. Hu, J. Busye, and Z. G. Song. 2021. Effects of cold stress on growth performance, serum biochemistry, intestinal barrier molecules, and adenosine monophosphate-activated protein kinase in broilers. Anim. 15:1–7.