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

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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

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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

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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 m^2/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

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 18°C	21°C	24°C	27°C	30°C	SEM	P-value	Linear	Quadratic
Body weight (g/bird)	3,367.94[a]	3,205.83[ab]	3,256.11[ab]	3,109.22[b]	2674.17[c]	65.55	<0.001	<0.001	0.006
Weight gain (g/bird/day)	86.39[a]	78.93[ab]	80.86[ab]	74.89[b]	54.28c	2.99	<0.001	<0.001	0.005
Feed intake (g/bird/day)	248.67[a]	233.83[a]	233.09[a]	212.23[b]	172.96c	5.61	<0.001	<0.001	0.003
Feed conversion ratio (feed/gain)	2.89[b]	2.98[b]	2.89[b]	2.85[b]	3.20a	0.07	0.014	0.042	0.045

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

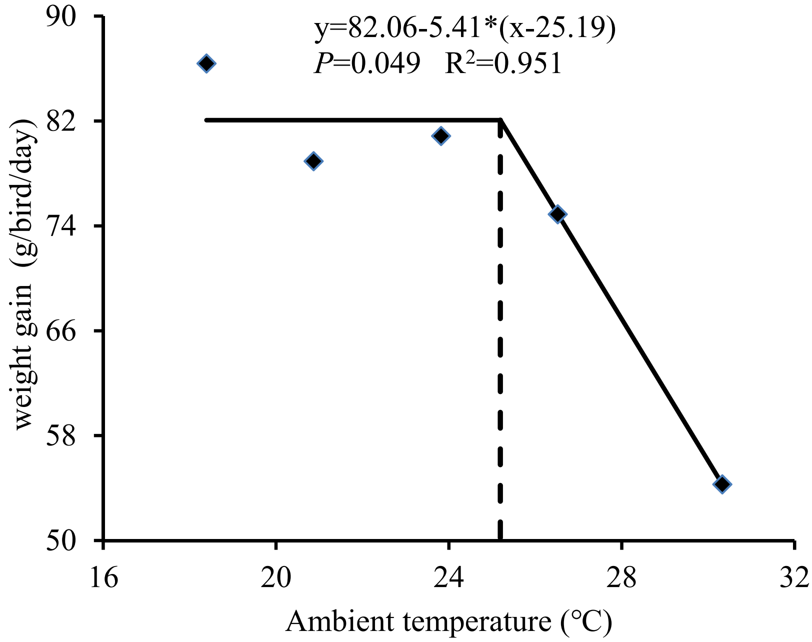

Figure 1. Weight gain response to ambient temperature of geese.

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 ± 2°C for 8 h/d and 22 ± 2°C for 16 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 for 8 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 (temperature was 34°C) increased fat content and decreased protein

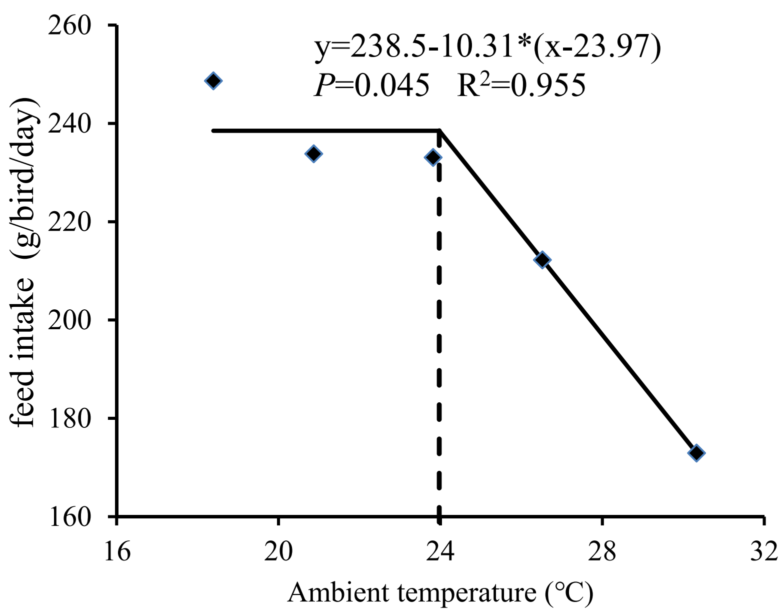

Figure 2. Feed intake response to ambient temperature of geese.

Table 2. Effects of ambient temperature on fat deposition of geese from 28 to 49 d of age.[1]

	Ambient temperature								
Item	18°C	21°C	24°C	27°C	30°C	SEM	*P*-value	Linear	Quadratic
Abdominal fat weight (g)	120.68[a]	97.83[ab]	102.90[ab]	89.92[b]	80.50[b]	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[a]	2.16[ab]	2.44[ab]	1.84[b]	1.75[b]	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 (dry matter basis %)	7.02	7.14	7.31	7.10	6.97	0.30	0.938	0.883	0.437
Liver fat content (dry matter basis %)	10.57	11.77	11.82	12.96	14.58	1.07	0.129	0.012	0.634

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

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

Table 3. Effects of ambient temperature on intestinal morphology of geese at 49 d of age.[1]

	Ambient temperature								
Item	18°C	21°C	24°C	27°C	30°C	SEM	*P*-value	Linear	Quadratic
Duodenum									
Villus height	841.91[ab]	954.51[a]	819.64[abc]	745.65[bc]	647.39[c]	58.26	0.014	0.003	0.110
Crypt depth	276.42	275.48	257.92	265.10	264.43	18.67	0.947	0.566	0.721
Villus width	87.24	81.86	81.56	80.06	79.23	5.07	0.839	0.283	0.680
Muscularis thickness	348.42	385.28	356.93	375.58	346.22	28.48	0.823	0.879	0.442
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	0.897	0.412	0.925
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	0.668	0.734	0.919
Muscularis thickness	182.68	216.80	213.88	222.69	198.56	21.51	0.688	0.585	0.205

[1]Results 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.

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DISCLOSURES

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

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