Heat stress impacts on broiler performance: a systematic review and meta-analysis

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ABSTRACT  Heat stress (HS) is a major problem in poultry business which affects chickens' performance and may trigger large economic losses. This study intends to analyze the impact of HS on broiler chickens' performance compared with those under normal condition. A literature search was performed on PubMed, Web of Science, and Cochrane Library for studies published in English up to January 17, 2020. Outcomes of body weight gain (BWG), feed intake (FI), feed conversion ratio (FCR), and mortality were calculated by weighted difference (WMD) or odds ratio (OR) with 95% confidence interval (CI). A total of 12 studies with 470 broiler chickens were included. HS significantly decreased FI (11 trials: WMD = −97.95, 95% CI: −141.70, −54.20) and BWG (7 trials: WMD = −151.40, 95% CI: −198.59, −104.21) and significantly increased FCR (9 trials: WMD = 0.17, 95% CI: 0.04, 0.29) and mortality (8 trials: OR = 3.74, 95% CI: 1.39, 10.12) compared with the control. In conclusion, HS significantly affected broiler chickens' BWG, FI, FCR, and mortality, indicating the importance to control housing temperature to avoid unnecessary costs.

Key words: heat stress, thermal condition, broiler chicken, feed intake, meta-analysis

INTRODUCTION

The poultry industry is important around the world that about 103.5 million tons of annual global chicken meat production accounted for 34.3% of the global meat production in 2012 (Pawar et al., 2016). Besides, chicken meat and eggs are regarded as the most efficient protein sources as well as a healthy alternative to red meat or other protein production systems (Williams et al., 2006). However, owing to the advance of global warming, heat stress (HS) has become a challenge for the poultry industry especially in tropical and subtropical regions (Gregory, 2010). Chicken is most vulnerable to HS for its inability to dissipate body heat production resulting from feather covering and limited sweat glands (Zhang et al., 2017). HS always contributes to a series of physiological disturbances, including systemic immune dysregulation, endocrine disorders, respiratory alkalosis, and electrolyte imbalance, which affect the health and performance of the chickens (Teeter et al., 1985; Sohail et al., 2010; Lara and Rostagno, 2013). Numerous researches have reported the negative influence of HS on poultry production, such as decreased body antioxidant capacity and intestinal immunity as well as impaired intestinal morphology (Sahin et al., 2017; He et al., 2018; Song et al., 2018).

A previous meta-analysis (da Fonseca De Oliveira et al., 2018) has revealed the impact of HS on swine performance in terms of average daily gain, average daily feed intake (FI), and feed gain ratio; another one (Grasteau et al., 2014) demonstrated the effect of HS on laying hens regarding genotype, age, group size, and amplitude of temperature variation. Broiler chicken is an important source of meat production; however, there is no meta-analysis study focused on the performance of broiler chickens exposed to HS. Therefore, the present study was conducted to analyze the impact of HS on broiler chicken by making a systematic review and meta-analysis on the published researches.

MATERIALS AND METHODS

This study was conducted following the PRISMA guidelines for reporting systematic review and meta-analysis.

Search Strategy and Study Selection

Keyword search was performed in PubMed, Web of Science, and Cochrane Library for studies published in
English up to January 17, 2020. The following keywords with mapping of term to subject headings and abstracts were used in the database search: HS, thermal condition, hot environment, high temperature, chicken, broiler, poultry, and performance. Titles or abstracts of the studies identified through the keyword search were screened against the study selection criteria. If the title and abstract failed to present adequate information to include or exclude the study for analysis, the study was reviewed in full text. Discrepancies were resolved by discussion meeting each week. Potentially relevant studies were retrieved for evaluation of the full text. Reference lists of retrieved articles were manually examined to further identify potentially relevant publications.

Inclusion criteria are as follows: (1) chicks either exposed to thermal conditions or thermoneutral conditions; (2) experiments were performed under controlled temperature conditions; (3) reported at least one of the endpoints including body weight gain (BWG), FI, feed conversion ratio (FCR), and mortality. Nonoriginal studies such as review, letter, and comment were excluded. For relevant studies that did not provide necessary data for analysis, we contacted the corresponding author of the articles for information. If we did not receive author’s response in a reasonable amount of time, the study was excluded.

Data Abstraction

After the initial review, data of potentially relevant articles were extracted by reviewers. A standardized data extraction form was applied to collect information on publication year, first author name, chick strain, number and age of chick for experiment, temperature for the HS group and normal control, period for experiment, and data related to BWG, FI, FCR, and mortality at the end of the experiment.

Statistical Analysis

STATA V12.0 (Stata Corporation, College Station, TX) was used to perform statistical analysis. Size effect of the continuous outcomes was calculated by weighted difference (WMD) with 95% confidence interval (CI), while that of the dichotomous outcomes were calculated by odds ratio (OR). Heterogeneity among studies were examined by Cochran’s Q statistic and I² test. Substantial heterogeneity occurred if $P$-value $< 0.05$ (Q statistic) and/or $I^2 > 50$, and then the random-effect model was applied, otherwise, the fixed-effect model was used. Sensitivity analysis was performed to confirm the robustness of the results and avoid arbitrary and unclear
Table 1. Characteristics of included studies.

| Study                     | Strain                                | No. of chick/group | Age for experiment (d) | Thermonutral conditions | Heat stress conditions               |
|---------------------------|---------------------------------------|--------------------|------------------------|-------------------------|--------------------------------------|
| Alhenaky et al., 2017     | Hubbard classic broiler chicks        | 24                 | 26                     | 20°C ± 2°C              | Chronic: 30°C ± 2°C, 24 h/d for 10 d, Acute: 35°C ± 2°C for 4 h and then returned back to the thermoneutral conditions |
| Aswathi et al., 2019      | CARIBRO-Vishal breeder hens           | 45                 | Not provided           | Normal temperature      | 37°C ± 1°C for 6 h/d up to 10 d       |
| Awad et al., 2020         | Cobb 500 and Ross 308 male broilers   | 60                 | 22                     | 23°C                    | 34°C, 6 h/d for 13 d                 |
| Del Vesco et al., 2017    | Cobb 500 male broilers                | 50                 | 20                     | 34°C for the first 7 d, decreased gradually to 27°C until day 20, and then decreased gradually to 18°C until day 42 | 38°C for 21 d                       |
| Goo et al., 2019          | Cobb 500 mixed                         | 285                | 21                     | 20°C for 14 d           | 27.8°C for 14 d                      |
| Imik et al., 2012         | Ross 308 mixed                         | 45                 | 15                     | 24°C for 20 d           | 34°C, 6 h/d for 20 d                 |
| Khatlab et al., 2018      | Cobb 500 mixed                         | 60                 | 22                     | 19°C for 19 d           | 38°C for 19 d                        |
| Ma et al., 2018           | Arbor Acres male broilers             | 48                 | 28                     | 22°C for 14 d           | 32°C for 14 d                        |
| Olfati et al., 2018       | Broiler chickens                       | 60                 | 22                     | 23.9°C ± 2°C for 22 d   | 33°C ± 3°C for 22 d                  |
| Quinteiro-Filho et al., 2010 | Broiler chickens                   | 80                 | 34                     | 21°C ± 1°C for 8 d     | 31°C ± 1/36°C ± 1°C, 10 h/d for 8 d  |
| Quinteiro-Filho et al., 2012b | Male breeder chickens               | 60                 | 35                     | 21°C ± 1°C for the entire day | 31°C ± 1°C for 10 h in the 35th d    |
| Sohail et al., 2012       | Ross-708 broilers mixed sex           | 90                 | 1                      | 35°C ± 2°C at day 1 and decreased 3°C per week until reached 26°C ± 2°C | 35°C ± 2°C for 42 d                 |

ones by omitting at least one study at a time. According to the Cochrane Handbook, risk of publication bias was assessed using Begg’s test if the included trials up to 10. A P value > 0.05 was considered as no publication bias.

RESULTS

Study Selection Process

A total of 4,107 studies were retrieved from the electronic databases, and 3 studies were identified through manual search. A total of 813 studies were excluded for duplicate, and the title and abstract of 3,297 studies were screened, among which a total of 3,249 studies were excluded for low relativity, inappropriate article type such as review, comment, and letter, without comparison, and involved other variables. A total of 48 studies were fully reviewed, and 36 were excluded for lack of data of interest. Finally, 12 studies were included in the analysis (Quinteiro-Filho et al., 2010; Sohail et al., 2010; Imik et al., 2012; Quinteiro-Filho et al., 2012a; Alhenaky et al., 2017; Del Vesco et al., 2017; Khatlab et al., 2018; Ma et al., 2018; Olfati et al., 2018; Aswathi et al., 2019; Awad et al., 2020; Goo et al., 2019). Details are presented in Figure 1.

Study Characteristics

There were 2 trials in the studies by Quinteiro (Quinteiro-Filho et al., 2010) and Alhenaky (Alhenaky et al., 2017), which were considered as independent studies for analysis. As shown in Table 1, Cobb 500 broiler chickens were used in 4 studies; Hubbard classic, Ross 308, Ross 708, CARIBRO-Vishal, and Arbor Acres were used in 5 studies; the rest 3 studies did not specify the strain of the broiler chicken. Temperature for the thermoneutral control group ranged from 18°C to 25.9°C, except in 2 studies with ladder-type control temperature decreasing from 34°C to 27°C to 18°C (Del Vesco et al., 2017) and from 37°C to 24°C (Sohail et al., 2012). Chronic HS was used in 9 studies, ranging from 28°C to 38°C for 8–22 d, while acute HS was used in 3 studies, ranging from 30°C to 38°C for 4–24 h. As only FI and FCR contained 10 trials, Begg’s test was performed on these endpoints, and the results showed that no publication bias was observed (P = 0.17; P = 0.94).

Feed Intake

A total of 11 trials from 10 studies (Quinteiro-Filho et al., 2010; Imik et al., 2012; Quinteiro-Filho et al., 2012a; Sohail et al., 2012; Del Vesco et al., 2017; Khatlab et al., 2018; Olfati et al., 2018; Aswathi et al., 2019; Awad et al., 2020; Goo et al., 2019) reported FI between HS and the control group. Substantial heterogeneity was observed, thereby the random-effect model was applied (I² = 99.4%, P = 0.00). As shown in Figure 2, FI was significantly decreased in the chickens exposed to HS compared with the normal control (WMD = −97.95, 95% CI: −141.70, −54.20).

Body Weight Gain

A total of 6 studies (Quinteiro-Filho et al., 2010; Quinteiro-Filho et al., 2012a; Sohail et al., 2012; Khatlab et al., 2018; Awad et al., 2020; Goo et al., 2019) with 7 trials reported BWG between HS and
the control group. The random-effect model was used because of substantial heterogeneity ($I^2 = 83.80\%, P = 0.00$). Figure 3 showed that HS significantly decreased the chickens’ BWG compared with the control (WMD = $-151.40$, 95% CI: $-198.59$, $-104.21$).

**Feed Conversion Ratio**

A total of 11 trials from 9 studies (Quinteiro-Filho et al., 2010; Imik et al., 2012; Quinteiro-Filho et al., 2012a; Sohail et al., 2012; Alhenaky et al., 2017;...
Ma et al., 2018; Olfati et al., 2018; Awad et al., 2020; Goo et al., 2019) reported FCR between HS and the control group. Substantial heterogeneity was observed and the random-effect model was used ($I^2 = 96.3\%$, $P = 0.00$). As presented in Figure 4A, there was no significant difference between groups (A), while feed conversion ratio was significantly increased in heat stress group if omitted Alhenaky 2017(2) and Quinteiro 2012 (B).

Ma et al., 2018; Olfati et al., 2018; Awad et al., 2020; Goo et al., 2019) reported FCR between HS and the control group. Substantial heterogeneity was observed and the random-effect model was used ($I^2 = 96.3\%$, $P = 0.00$). As presented in Figure 4A, there was no significant difference between groups (A), while feed conversion ratio was significantly increased in heat stress group if omitted Alhenaky 2017(2) and Quinteiro 2012 (B).

### Mortality

A total of 6 studies (Quinteiro-Filho et al., 2010; Quinteiro-Filho et al., 2012a; Sohail et al., 2012; Quinteiro-Filho et al., 2012b) reported mortality between HS and the control group. Substantial heterogeneity was observed and the random-effect model was used ($I^2 = 95\%$, $P = 0.00$). As presented in Figure 4B, there was no significant difference between groups (A), while mortality was significantly increased in heat stress group if omitted Quinteiro 2012a (B).

### Figure 4.

The forest plot of feed conversion ratio between the broiler chickens exposed to heat stress and thermoneutral condition. No significantly difference was observed between groups (A), while feed conversion ratio was significantly increased in heat stress group if omitted Alhenaky 2017(2) and Quinteiro 2012 (B).

| Study          | WMD (95% CI) | Weight |
|----------------|--------------|--------|
| Alhenaky 2017(1) | 0.08 (-0.01, 0.17) | 18.21  |
| Alhenaky 2017(2) | 0.53 (0.46, 0.60) | 13.79  |
| Awad 2019       | 0.16 (-0.03, 0.35) | 13.27  |
| Goo 2019        | 0.00 (-0.20, 0.20) | 19.61  |
| Imik 2012       | -0.00 (-0.04, 0.04) | 16.03  |
| Ma 2018         | 0.38 (0.24, 0.52) | 2.47   |
| Olfati 2018     | 0.56 (-0.00, 1.12) | 3.17   |
| Quinteiro 2010(1) | 0.05 (-0.69, 0.79) | 12.34  |
| Quinteiro 2010(2) | 1.06 (-1.05, 3.17) | 0.34   |
| Overall (I-squared = 96.3\%, $P = 0.00$) | 0.12 (-0.10, 0.35) | 100.00 |

| Study          | WMD (95% CI) | Weight |
|----------------|--------------|--------|
| Alhenaky 2017  | 0.08 (-0.01, 0.17) | 13.79  |
| Awad 2019      | 0.16 (-0.03, 0.35) | 16.03  |
| Goo 2019       | 0.00 (-0.20, 0.20) | 2.47   |
| Imik 2012      | -0.00 (-0.04, 0.04) | 12.34  |
| Ma 2018        | 0.38 (0.24, 0.52) | 0.34   |
| Olfati 2018    | 0.56 (-0.00, 1.12) | 100.00 |
| Quinteiro 2010(1) | 0.05 (-0.69, 0.79) | 12.34  |
| Quinteiro 2010(2) | 1.06 (-1.05, 3.17) | 0.34   |
| Overall (I-squared = 96.3\%, $P = 0.00$) | 0.12 (-0.10, 0.35) | 100.00 |

**NOTE:** Weights are from random effects analysis.
with 8 trials reported chicken mortality between HS and control group. The fixed-effect model was used because of less heterogeneity ($I^2 = 0\%$, $P = 0.95$). As shown in Figure 5, HS significantly increased mortality compared with the control (OR = 3.74, 95% CI: 1.39, 10.12).

**DISCUSSION**

In the current meta-analysis with 12 included studies, we found that HS significantly decreased BWG and FI and significantly increased FCR and mortality in broiler chickens.

It is reported that HS induces the secretion of stress hormones, which alter the chickens' neuroendocrine system by activating the hypothalamic-pituitary-adrenal axis and thereby increasing the plasma corticosterone levels (Quinteiro-Filho et al., 2012b). Corticosterone is associated with a higher degree of body protein breakdown (Yunianto et al., 1997), which affects the digestive system, nutrient utilization, and digestibility (Olfati et al., 2018). Furthermore, HS has been reported to disturb intestinal barrier function, lead to inflammatory responses, and compromise performance. A study by Alhenaky et al. (2017) showed that HS, whether chronic or acute, impaired intestinal integrity and increased intestinal permeability to endotoxins and *Salmonella* spp, which may explain the higher mortality in the HS group than the control in the present study.

In addition, modern broiler chickens are genetically selected strains with better growth rate, which is associated with higher FI. Under HS conditions, however, chickens may spend more energy for maintenance and acclimation, which thereby reduce the energy for growth and lead to a decrease in BWG (Mujahid et al., 2007), which is consistent to our findings as well as the previous meta-analysis on layer hens (Grasteau et al., 2014).

FCR did not show significant differences between HS and the control group. However, HS group would presented significantly higher FCR with less heterogeneity than the control if excluded (Quinteiro-Filho et al., 2012a and Alhenaky et al., 2017). After reviewing these 2 studies, we found that the HS strategies used in both studies were acute stress that lasted less than 24 h, while other studies used chronic stress that lasted for 8 to 42 d, which may explain the changes identified from sensitivity analysis and reveal that HS may lead to more costs on animal feed. Nevertheless, exclusion of these 2 studies did not lead to significant changes in other endpoints.

There are some limitations within the present study. First, owing to the small number of included studies, we were unable to perform subgroup analysis based on broiler strain, HS temperature, and age for experiment. Second, significant heterogeneity was common in the endpoints which may lead by the difference of temperature strategy in each study. In conclusion, this study revealed the negative impacts of high temperature on broiler chickens regarding BWG, FI, FCR, and mortality, indicating the importance and emergency for the poultry industry to seek a way to mitigate the temperature influence and prevent economic losses.
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