Review

Strain-Specific Heat Stress Responses in Broiler Chickens Under Climate Change: A Systematic Review

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Abstract | This study systematically reviewed published research on the responses of broiler strains to heat stress associated with climate change. Databases included Scopus, Google Scholar, Taylor and Francis, Wiley, and Springer with the keywords: broiler, thermal environment, climate change, temperature, heat stress, and performance. The articles included were published from 2000 until 2024. The results showed 48 relevant articles identified from different regions: Asia, Europe, the Americas, and Africa. The most frequently studied broiler strains were Ross 308 (n=14), Arbor Acres (n=11), and Cobb 500 (n=7). Results indicated that heat stress was consistently associated with reduced feed intake, lower body weight gain, impaired feed conversion, and increased mortality. Strain-specific responses varied: Ross 308 tended to show smaller reductions in feed intake, Hubbard maintained more stable ADG and FCR, whereas Arbor Acres and Line A showed greater performance declines. These variations were influenced by genetic background, bird age, environmental conditions, and experimental design, with none of the strains demonstrating absolute tolerance. This review emphasizes the importance of accounting for strain-specific variation in heat tolerance as part of adaptive management strategies, and highlights the need for further research on local and crossbred strains to support sustainable poultry production under a warming climate.

Keywords | Broiler, Climate, Heat stress, Strain, Systematic review, Temperature

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INTRODUCTION

Climate change has become a major global issue and a focal point of international concern (Abbasi and Nawaz, 2020). This phenomenon encompasses a range of significant changes in Earth's atmospheric conditions, including overall temperature increases, unpredictable weather pattern fluctuations, and a higher frequency of extreme weather events, many of which are highly destructive. These climatic disruptions have resulted in rising average temperatures across many regions of the world (Cassandro, 2020). The livestock sector, particularly broiler chicken production, is among the most affected industries (Jiang et al., 2021).

Broiler chickens play a key role in meeting the growing demand for animal-based protein. The primary goal of broiler farming is to produce high-quality meat with rapid growth rates (Devatkal *et al.*, 2019). Successful broiler production is highly dependent on maintaining a comfortable and controlled environment. Broilers, as homeotherms can maintain a constant internal body temperature despite environmental changes. The average body temperature of adult broilers ranges from 40 °C to 42 °C, while their thermal comfort zone lies between 21 °C and 24 °C (Scanes and Christensen, 2020). When exposed to high ambient temperatures combined with elevated humidity, broilers struggle to dissipate body heat effectively. This condition leads to heat stress (Ajakaiye *et al*., 2010; Wang *et al*., 2020).

The physiological consequences of heat stress include reduced feed intake, impaired weight gain, reproductive disturbances, and metabolic and physiological disorders (Nawaz *et al*., 2021). In addition, heat stress increases the risk of disease. Broilers experiencing prolonged heat stress typically exhibit weakened immune responses, making them more susceptible to bacterial and viral infections. Chronic and severe heat stress conditions can significantly worsen the health status of chickens and may ultimately lead to death due to extreme thermal exposure (Lacetera, 2019).

The response of broilers to heat stress is highly influenced by genetic strain. Commercial strains such as Ross, Cobb, and Arbor Acres demonstrate varying degrees of adaptability to high temperatures (Bueno *et al*., 2020; Chand *et al*., 2018). These genetic factors determine production performance, feed conversion efficiency, and tolerance to environmental stress. As a result, selecting heat-tolerant strains is considered a key adaptive strategy to cope with climate change. This must also be supported by improved housing management, nutritional regulation, and rigorous microclimate control (Zulfan and Zulfikar, 2020).

Although many studies have evaluated the effects of heat stress on broiler chickens, there remains a lack of systematic reviews comparing strain-specific responses under climate change conditions. No comprehensive analysis has yet compiled and assessed data across studies to identify which strains demonstrate superior adaptive traits, both physiologically and productively. Several previous systematic literature reviews conducted by Liu et al. (2020) and Siddiqui et al. (2022), discussed the impact of heat stress on broiler chickens, but their discussions were general in nature and did not present direct comparisons between strains based on chicken productivity indicators such as body weight gain, feed consumption, and mortality. To date, no systematic review has been found specifically examining differences in heat tolerance between strains using these parameters. Therefore, the objective of this study is to conduct a systematic review of existing literature concerning heat stress responses in broiler chickens based on genetic strain, with a focus on its implications for adaptive management strategies in the context of global climate change.

MATERIALS AND METHODS

Identification article and screening

This systematic review was conducted based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Haddaway et al., 2022). The selection process followed a structured approach involving article identification, screening, eligibility assessment, and final inclusion (Figure 1).

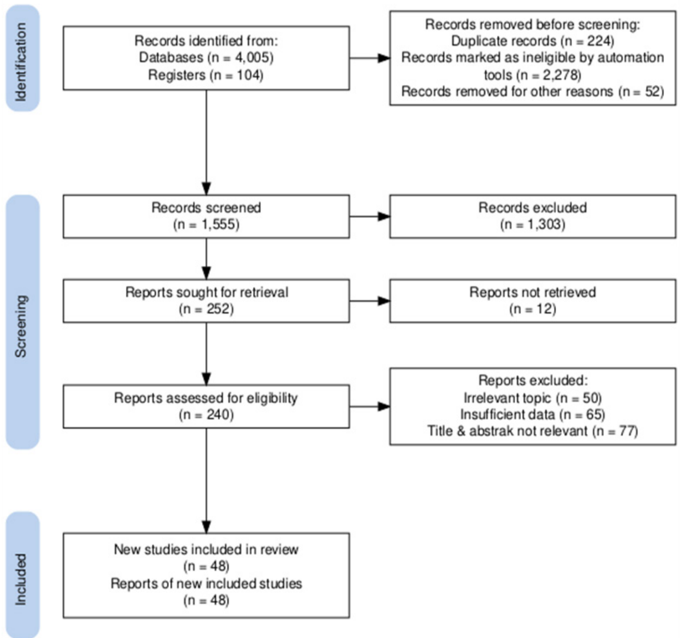

Figure 1: PRISMA 2020 flow diagram showing the study selection process for this systematic review on broiler chicken strains under heat stress (2000–2024).

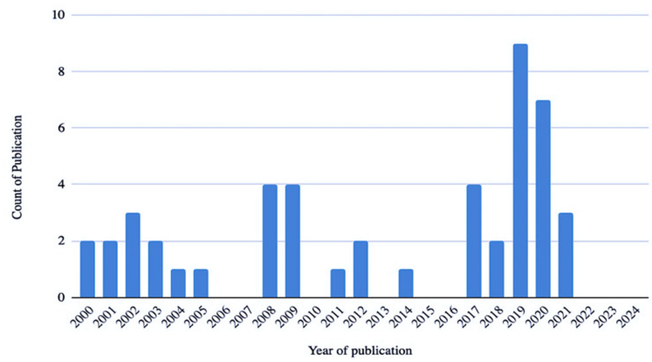

Figure 2: Annual publication trends of broiler heat stress studies from 2000 to 2024.

The search articles used for systematic literature reviews that have been published in databases include Scopus, Google Scholar, Taylor and Francis, Wiley, and Springer. The selected article includes peer-reviewed journal articles. Keywords used include ‘broiler’, ‘thermal environment, ‘climate change’, ‘temperature’, ‘heat stress’, and ‘performance. Peer-reviewed articles published from 2000 to 2024 were in the search strategy (Figure 2).

Table 1: Criteria for inclusion and exclusion of literature.

Criteria	Included	Excluded
Publishing year	Peer-reviewed Journal article ranged from 2000 to 2024	Journal articles published outside of 2000-2024.
Language of publication	Journal articles written in English that have been peer reviewed	Non-English Articles
Types of Articles	Articles that have been peer-reviewed can be accessed in full text by the authors.	Non-peer-reviewed journals and articles not given in full text to the author
Accessibility of articles	Electronic databases (Scopus, Wiley, Google Scholar, Taylor and Francis) provide access to articles.	These databases are not available.
The main theme of the publication	Articles concerning the impact of climate change on heat stress and thermal temperature in broilers	Articles that did not specifically focus on the impacts of climate change in broilers on heat stress and thermal temperature

Based on the PRISMA diagram (Figure 1), the literature search process identified 4,109 articles (4,005 from databases and 104 from registers). Subsequently, 224 duplicate articles were removed, 2,278 articles were excluded by automation, and 52 articles were removed because they were non-journal publications or lacked complete metadata, leaving 1,555 articles for screening.

During the title and abstract screening stage, 1,303 articles were excluded because they were considered irrelevant or not original research. Furthermore, 252 articles were screened in the full-text search stage, and 12 articles could not be accessed due to paywalls or unavailable files. A total of 240 full-text articles were assessed for eligibility. Of these, 192 articles were excluded because the topic was not relevant (n=50), the data was incomplete (n=65), or the title or abstract was not relevant (n=77). Finally, 48 articles met the criteria for inclusion in the studies.

Criteria for eligibility

The criteria for inclusion and exclusion were utilized as a guide in the article selection process Table 1. The articles that were not connected to broiler chickens or high temperatures and were outside of the scope of the research were removed. This study only used peer-reviewed articles and excluded review articles. Articles restricted to the English language and those lacking full text were excluded from the study.

RESULT AND DISCUSSION

Geographic origin of the literature

As shown by the article area collected in 48 articles in Figure 3, the majority of Asia (n= 27) is followed by Europe (n= 11), South/North America (n= 9), and Africa (n= 1). A total of 27 studies were conducted in Asia, the majority of which came from China (17), Pakistan (3), Israel (2), Saudi Arabia, Thailand, Japan, Iran, and Jordan. The European continent research came from Turkey (9), with two countries each from Spain and Italy. North American countries include the United States (7), whereas South American countries include Brazil (2), and the African region includes Egypt.

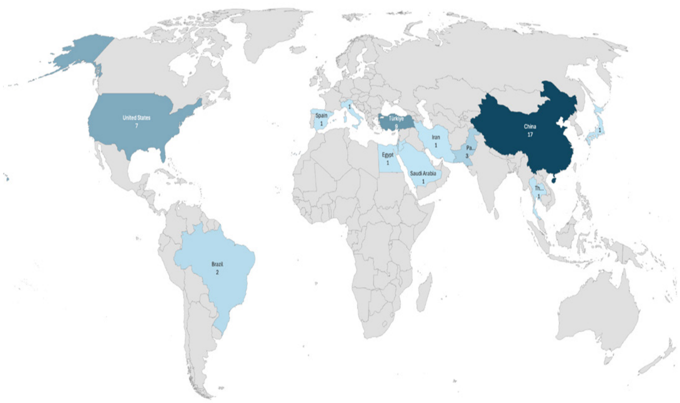

Figure 3: Geographic distribution of included studies

Of the 48 studies, only 47 were included in the strain-specific analysis of heat stress. One study (Heckert *et al.*, 2002) was excluded because it did not report specific heat stress temperatures. The results of the 48-article research found that the number of chicken strains used varied. Ross, Arbor Acres, Cobb, Yellow Feather, Hubbard, Chunky, Avian, White Rock, White Recessive Rock, Lingshan, Cockerels, G1, G2, G3, Line A, and Line B are the chicken breeds used. The majority of used chicken strains in the study are Ross (n = 14), which includes Ross 308 (12) and Ross 708 (2). Arbor Acres (n = 11), Cobb (n = 7), Yellow Feathers (n = 3), Hubbard (n = 4) includes Hubbard (3) and Hubbard Flex, and G1, G2, G3 (2). It includes eight strains from White Recessive Rock, Lingshan, White Rock, Cockereles, Chunky, Avian, Line A, and Line B strain. One study used a cross between the Ross 308 strain and Arbor cross strain. Each strain has different genetic characteristics in each region and can influence different responses to hot temperatures.

However, the inclusion of only one study from Africa limits the generalizability of these findings to all tropical regions, particularly Sub-Saharan Africa, which exhibits diverse climatic conditions and poultry management practices. Accordingly, further research in this region is warranted to enhance the global understanding of broiler strain responses to heat stress.

Broiler chicken strains and their genetic response to heat stress

The number of broiler chicken strains used in 48 articles varies and are presented in Table 2. The strains used include Ross (308, 708), Arbor Acres, Cobb, Yellow Feather, Hubbard, Chunky, Avian, White Rock, White Recessive Rock, Lingshan, Cockerels, G1, G2, G3, Line A, and Line B. The most used strains are Ross 308 (11 studies) and Arbor Acres (11 studies), followed by Cobb (7 studies), which consists of Cobb 500 (4) and Cobb (3). Other strains include Yellow Feather (3), Hubbard (3), Ross 708 (2), and Hubbard Flex. There are also seven strains each of White Rock, White Recessive Rock, Lingshan, Cockerels, Chunky, Avian, and unique strains G1, G2, and G3. One study used a crossbreed between Ross and Cobb strains.

In the study by Heckert *et al.* (2002), which used avian strains, the specific temperature applied for heat stress was not reported. Therefore, this study was acknowledged as part of the strain variation but was excluded from the strain-specific comparative analysis with respect to heat stress temperature. Each strain has different genetic characteristics depending on the region, which can influence their varied responses to heat stress. Ross and Arbor Acres strains are known to have better adaptation to heat stress, showing resilience in growth rate, feed conversion, and survival rate (Niu *et al.*, 2009; Sahin *et al.*, 2017a; Yan *et al.*, 2019a).

Temperature range and experimental parameters

The thermoneutral zone for chickens is generally between 22–24 °C (Table 2), with an optimal upper limit around 26 °C. Temperatures above this range indicate that chickens are experiencing heat stress. In this study, heat stress temperatures varied between 29 °C and 41 °C, with exposure durations ranging from 1 to 24 hours per day.The common methods of heat exposure used in this research include cyclic temperature exposure, where high temperatures are applied only for several hours per day. Continuous temperature exposure, where high temperatures are maintained for a full 24 hours (Bartlett and Smith, 2003). The study showed that even heat exposure of less than 6 hours per day already caused a decline in chicken performance. The observed impacts include decreased feed intake, reduced body weight gain, poorer feed conversion ratio, and disturbances in metabolism and immunity (Lu *et al.*, 2019a).

Age and growth phases of chickens

The experimental age are presented in Table 2 and mostly ranges from 21 to 42 days. The use of this age range is because the chicken's organs have begun to develop, and nutritional needs are focused on growth, which is the main focus, unlike in the early stages of rearing (He *et al.*, 2019a; Lan *et al.*, 2020). Different ages of chickens have different nutritional requirements, thermoregulation systems, and immune responses. Juvenile chickens have an immature regulatory system, making them more vulnerable to external temperature changes. In the early development phase, chickens require a warm environment for their growth process. As they age, chickens develop better regulatory systems to adapt to environmental temperature changes. However, when the environmental temperature exceeds the chicken's normal threshold, they can experience heat stress, which negatively impacts their productivity and welfare (Burkholder *et al.*, 2008; Greene *et al.*, 2021; Niu *et al.*, 2009; Souza *et al.*, 2016; Yalcin et al., 2003).

Chicken performance

Exposure to high temperatures negatively affects the performance of broiler chickens (Table 2). According to research studies, chickens exposed to temperatures above 32°C for more than six hours per day experience a decrease in feed intake, body weight gain, feed conversion efficiency, and an increase in mortality rates (Hu *et al.*, 2017; Majdeddin *et al.*, 2020; Yan *et al.*, 2019; Zhang *et al.*, 2017).

Strain-specific responses to heat stress varied: Ross 308 tended to show smaller reductions in feed intake, Hubbard maintained more stable ADG and FCR, whereas Arbor Acres and Line A were more adversely affected. At 32°C for 9 hours, the Ross 308 strain still achieved a final weight of 2600 g with an FCR of 2.32 and a mortality rate of 5.3% (Yan *et al.*, 2019). The Arbor Acres strain at a temperature of 32-35°C experienced a decrease in feed consumption and body weight gain; however, the FCR remained in a lower range (2.14-2.32) compared to the Cobb strain, which reached 2.53 with a significant decrease in body weight at a temperature of 33 °C for 10 hours (Hu *et al.*, 2017; Zhang *et al.*, 2017). The decline in feed conversion efficiency occurs because the energy in chickens is increasingly used to maintain a stable body temperature (Burkholder *et al.*, 2008). Additionally, mortality rates also rise, especially in the Ross 308 and Cobb 500 strains. Both strains show a sharper decline in performance and higher mortality rates when environmental conditions cannot be optimally controlled (Song *et al.*, 2014; Greene *et al.*, 2021). These differences indicate that strain resilience is not solely determined by genetics but is also influenced by bird age, study design, heat exposure protocols (cyclic or constant), duration of exposure, and nutritional interventions tested in some studies. Physiologically, heat stress is characterized by increased body temperature, elevated respiratory rate, and disrupted metabolism and homeostasis in chickens.

Table 2: Characteristic of the selected studies on strain-specific heat stress responses in broiler chickens.

Authors	Strain	The number of chickens	Age for experiment (day)	TN Temp (°C)	HS Temp. (°C)	Performance Parameter	TN Performance	HS Performance	Observed Effect
He *et al.* (2019a)	Arbor Acres	200	28 to 42	22	32	ADG, ADFI, FCR	ADFI:122.26 g/bird/day; ADG:59.26 g/bird/day, FCR: 2.14	ADFI:101.58 g/bird/day, ADG:41.48 g/bird/day, FCR: 2.53	ADFI and ADG ↓; FCR ↑
Yan *et al.* (2019)	Ross 708	360	15 to 42	22	32 (9 h)	BW	NR	BW: 2600 g	BW ↓
Xu *et al.* (2018)	White recessive rock, lingshan	90	28	26	34 (9 h)	NR	NR	NR	NR
Lu *et al.* (2019)	Arbor Acres	144	28 to 42	22	32	BW, ADFI, ADG, and FCR	BW: 1901.46 g; ADFI : 120.26 g/bird/day; ADG : 57.36 g/bird/day; FCR: 2.11	BW:1674.10 g; ADFI:100.98 g/bird/day; ADG:40.37 g/bird/day; FCR: 2.52	BW, ADFI, and ADG ↓; FCR ↑
Greene *et al.* (2019)	Cobb 500	60	21 to 42	24	29.5	NR	NR	NR	NR
Wu *et al.* (2018)	Arbor Acres	360	22 to 41	22	36 (for 10 h from 8:00-18:00)	NR	NR	NR	NR
Sahin *et al.* (2017)	Ross 308	1200	22 to 42	22	34 (for 9 h from 8:00-17:00	FI, WG, FCR	FI: 3669 g; WG: 2059 g; FCR : 1.79	FI: 3224 g;WG: 1625 g; FCR: 1.99	FI and WG ↓; FCR ↑
Zhang *et al.* (2017)	Cobb	270	21 to 42	22	33 for 10 h	FI, ADG, FCR, BW	ADFI: 129.7 g/bird/day; ADG: 61.60 g/bird/day; FCR: 2.10; Final BW:1966.4 g	ADFI: 116.8 g/bird/day; ADG: 52.32 g/bird/day; FCR: 2.24; Final BW: 1784.0 g	ADFI, ADG and Final BW ↓; FCR ↑
Hu *et al.* (2017)	Arbor Acres	36	16	20	35 (for 6 h from 12:00-18:00)	BW, ADFI, ADG, and FCR	BW: 1300 g; ADFI: 125 g/bird/day; ADG: 50 g/bird/day; FCR: 2.10	BW: 1150 g; ADFI: 121 g/bird/day; ADG: 30 g/bird/day; FCR: 3.90	BW, ADFI and ADG ↓; FCR ↑
Song *et al.* (2014)	Ross 308	360	22 to 42	22	33 (for 10 h from 8:00-18:00)	ADG, ADFI,FCR	ADG : 77.7 g/bird/day; ADFI: 158 g/bird/day; FCR: 2.03	ADG: 70.7 g/bird/day; ADFI: 148 g/bird/day; FCR: 2.10	ADG and ADFI ↓; FCR ↑
Carro *et al.* (2009)	Ross × Cobb	10	35 to 70	25	41	NR	NR	NR	NR
Sohail *et al.* (2012)	Ross 708	450	21 to 42	26	35	FC, BWG, FCR, Mortality	FC: 3214.5 g; BWG: 2411.3 g; FCR: 1.33; Mortality: 5.56 %	FC: 2688.8 g; BWG: 1626.3 g; FCR: 1.67; Mortality:10.00 %	FC and BWG ↓; FCR and Mortality ↑
Burkholder *et al.* (2008)	Ross 308	960	21 to 42	23	30 (for 24 h)	NR	NR	NR	NR
Ahmad *et al.* (2008)	Hubbard	150	14 to 42	29	33	FI, BW, FCR	NR	FI: 3260.3 g; BWG: 1584.3 g; FCR: 2.06	FI and BWG ↓ ; FCR ↑
Yalçin *et al.* (2009)	Ross 308	900	21 to 42	22	32 (for 8 h from 12:00-17:00)	NR	NR	NR	NR

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Links Researchers

Authors	Strain	The number of chickens	Age for experiment (day)	TN Temp (°C)	HS Temp. (°C)	Performance Parameter	TN Performance	HS Performance	Observed Effect
Yalçin *et al.* (2008)	Ross 308	900	21 to 42	22	32 (for 8 h from 12:00-17:00)	BW, Mortality	BW: 2274 g; Mortality: 4.50 %	BW: 2229 g; Mortality: 7.70 %	BW ↑; Mortality ↑
Niu *et al.* (2009)	Arbor Acres	240	21 to 42	23.9	38 (for to 12 h, 3 h, 5 h, 4 h)	BW, FI,FCR	BW: 1998.81 g; FI: 3550.41 g; FCR: 1.81	BW:1540.81g; FI: 3100.03g; FCR: 2.05	BW and FI ↓; FCR ↑
Deeb and Cahaner (2001a)	White rock	120	44 to 49	22	32 for 24 h	BW, WG, FC, FE	Dwarf; BW: 1506g; WG: 39.8 g/d; FC: 130g; FE; Normal; BW: 1963 g; WG: 54.2 g/d; FC: 162 g/d	Dwarf; BW: 1614 g; WG: 25.8 g/d; FC: 94 g; Normal; BW: 2060 g; WG: 35.6 g/d; FC: 118 g/d	BW, WG and FC ↓
Deeb and Cahaner (2001b)	G1,G2, G3	500	21 to 53	25	33	BW	BW: 2322 g	BW: 1941 g	BW ↓
Deeb and Cahaner (2002)	Sire-line stock	240	21 to 42	22	32	WC, FC BW, WG, FE	WC: 220 g/d FC :152.4 g/d BW: 2103 g WG : 67.0 g/d FE : 0.441g/g	WC: 230 g/d FC :93.0 g/d BW: 1406 g WG : 26.6 g/d FE : 0.283 g/g	WC ↑; FC, BW,WG and FE ↓
Heckert *et al.* (2002)	Avian	2400	22 to 42	22	NR	BW	NR	NR	NR
Bartlett and Smith (2003)	Arbor Acres	144	21	23.9	37 (for to 12 h, 3 h, 6 h, 3 h)	BW, FI, FCR	BW : 1726.83 g; FI: 3643.92 g; FCR : 2.11	BW: 1387.20 g; FI: 3240.33 g; FCR : 2.34	BW and FI ↓; FCR ↑
Slawinska *et al.* (2020)	Ross 308	900	32 to 42	22	30	BW, FI, DWG, DFI,FCR, Mortality	BW: 3110 g; FI: 4810 g; DWG: 71.79 g/bird/day; DFI: 114.6 g/bird/day; FCR: 1.597; Mortality: 4.93 %	BW: 2520 g; FI: 4310 g; DWG: 58.77 g/bird/day; DFI: 102.6 g/bird/day; FCR: 1.749; Mortality: 10.00%	BW, FI, DWG and DFI ↓; FCR and Mortality ↑
He *et al.*, (2019b)	Yellow feather	288	28 to 42	24	37	NR	NR	NR	NR
Miao *et al.* (2020)	Arbor Acres	144	27 to 35	26	29 ,32 ,35 (each for 6 h)	NR	NR	NR	NR
Majdeddin *et al.* (2020)	Ross 308	720	25 to 39	22	34 (for 7h from 8:00-16:00)	BW, ADG, ADFI, FCR, Mortality	NR	Final BW: 3018 g; ADG:103 g/bird/day; ADFI: 180 g/bird/day; FCR: 1.76; Mortality(%): 6.10 %	BW,ADG and ADFI ↓; FCR and Mortality ↑
Maharjan *et al.* (2020)	Line A, Line B	2025	22 to 42	22	29.6 (for 24 h)	BW, ADG, FI, FCR	Line A BW: 3180 g; ADG:109 g/bird/day; FI: 3760 g; FCR: 1.59 Line B BW: 3350 g; ADG: 113 g/bird/day; FI: 3930 g; FCR: 1.59	Line A BW: 2740 g; ADG : 81 g/bird/day; FI: 3293 g; FCR: 1.96 Line B BW: 2890 g; ADG: 90 g/bird/day; FI(g): 3590 g; FCR: 1.95	Line A: BW, ADG and FI ↓ ; FCR↑ Line B: BW, ADG and FI ↓; FCR ↑
Lan *et al.* (2020)	Yellow Feather	108	1 to 35	24	34 (for 8h from 10:00-18:00)	NR	NR	NR	NR

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Authors	Strain	The number of chickens	Age for experiment (day)	TN Temp (°C)	HS Temp. (°C)	Performance Parameter	TN Performance	HS Performance	Observed Effect
Greene *et al*. (2021)	Cobb	600	21 to 42	24	35 (for 12 h from 8:00-20:00)	NR	NR	NR	NR
Liu *et al*. (2021)	Yellow Feather	144	56	23.6	33.2	NR	NR	NR	NR
Alhotan *et al*. (2021)	Ross 308	150	21	22	33	NR	NR	NR	NR
Sahin *et al*. (2002)	Cobb 500	120	1 to 42	NR	32	NR	NR	NR	NR
Pamok *et al*. (2009)	NR	100	7 to 21	26	38	NR	NR	NR	NR
Alhenaky *et al*. (2017)	Hubbard	72	26 to 35	20	30 (for 24 h) 35 (for 4 h from 9:00-13:00)	BW, Final BW, ADG, FI,FCR, Mortality	BW: 1607 g; Final BW:1992.50 g; ADG: 67.63 g/bird/day; ADFI: 128.10 g/bird/day; FCR: 1.89; Mortality: 0.00%	Chronic heat stress (30oC); BW: 1448.75 g; Final BW: 1945.00 g; ADG: 65.88 g/bird/day; ADFI: 129.60 g/bird/day; FCR: 1.97; Mortality:0.00 %; Acute heat stress (35 4h/day); BW: 1352.50 g; Final BW: 1803.75 g; ADG: 57.75 g/bird/day; ADFI: 140.70 g/bird/day; FCR: 2.42; Mortality:33.30 %	BW, Final BW, ADG and ADFI ↓; FCR and Mortality ↑
He *et al*., (2019c)	Arbor Acres	200	28 to 42	22	32	NR	NR	NR	NR
El-Naggar *et al*. (2019)	Ross 308, Cobb 500	192	21 to 35	24	33 for 5 h	NR	NR	NR	NR
El-Deep *et al*. (2019)	Chunky	24	15 to 30	22	35 for 9 h	Final BW, BWG, FI,FCR,	Final BW: 1341.5 g BWG: 810.5 g FI: 1323.8 g FCR: 1.63	Final BW: 1207.6 g BWG: 601.7 g FI: 1073.04 g FCR: 1.52	Final BW, BWG, FI, and FCR ↓
Ahmad *et al*. (2005)	Hubbard	297	8 to 42	NR	29.3-38	WG, FI, FCR, Water intake, Mortality	NR	WG: 573 g FI: 1198 g FCR: 2.10 Water intake: 3933 ml/bird Mortality: 18.00 %	WG and FI, ↓; FCR, Water intake and Mortality ↑
Seven *et al*. (2008)	Ross 308	660	1 to 41	24	34	BW, BWG, FI, FCR, Mortality	BW: 2150 g BWG: 55 g FI: 112 g FCR: 2.0 Mortality: 2.50 %	BW:1940 g BWG: 49 g FI: 103 g FCR: 2.0 Mortality: 10.00 %	BW, BWG, and FI ↓; FCR relative stable; Mortality ↑
Dai *et al*. (2011)	Arbor Acres	360	22 to 42	24	30-34 (for 9 h from 9:00-18:00)	BW, WG, FC, FCR	BW: 2675 g WG: 1956 g FC: 4426 g FCR: 2.26	BW: 1810 g WG: 1087 g FC: 2568 g FCR: 2.36	BW, WG and FC ↓; FCR ↑

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Authors	Strain	The number of chickens	Age for experiment (day)	TN Temp (°C)	HS Temp. (°C)	Performance Parameter	TN Performance	HS Performance	Observed Effect
Yalçin *et al.* (2003)	Cockerels	360	21 to 42	21.5	32-35 (for 7 h from 10:00-17:00)	NR	NR	NR	NR
Yalçin *et al.* (2004)	Ross 308	510	21 to 56	19.5	32.8	BW	BW : 3674 g	BW(g) : 2977	BW ↓
Bai *et al.* (2019)	Arbor Acres	300	22 to 35	24	34 (for 8 h)	BW, BWG, FI,FCR	BW: 1598.4 g BWG: 931.4 g FI: 1765.6 g FCR: 1.90	BW: 1477.8 g BWG: 776.3 g FI: 1638.2 g FCR: 2.12	BW,BWG and FI ↓; FCR ↑
Souza *et al.* (2016)	Cobb 500	450	21 to 42	22	32	FI, BWG, FCR, Mortality	FI: 3369 g BWG: 2021 g FCR: 1.67 Mortality : 2.23 %	FI: 2498 g BWG: 1257 g FCR: 1.99 Mortality : 2.23 %	BWG and FI ↓; FCR and Mortality ↑
Ma *et al.* (2019)	Arbor Acres	90	29 to 42	21	31	NR	NR	NR	NR
Bueno *et al.* (2020)	Cobb, Hubbard Flex	1120	14 to 42	24,8-27	32.3-35.1 (for each 1 h from 11:00-12:00, for 2 h from 11:00-13:00, for 3 h from 11:00-14:00)	WG	Cobb WG: 0.70 kg Hubbard Flex WG: 0.64 kg	Cobb WG: 0.64 kg (1h) WG : 0.61 kg (2h) WG : 0.66 kg (3h) Hubbard Flex WG: 0.74 kg (1h) WG :0.61kg(2h) WG : 0.65 kg (3h)	FI,WG and Live Weight ↓; FCR ↑; Viability relative stable
Günal (2013)	Ross 308	240	28 to 42	NR	32-35 (for each 7 h from 10:00-17:00)	BW, FI, FCR, Mortality	NR	BW: 1014 g FI: 3254.21 g/bird FCR :1.95 Mortality: 8.75 %	BW and FI ↓; FCR and Mortality ↑
Yalcin *et al.* (2001)	G1, G2, G3	1800	28 to 49	NR	32-35 from from 10:00-17:00)	BW, FCR, Mortality	NR	BW: 2283 g FCR: 2.32 Mortality: 5.33 %	BW ↓; FCR and Mortality ↑

Note: TN Temp = Thermoneutral Temperature; HS Temp = Heat Stress Temperature; NR = Not Reported; ADG = Average Daily Gain; ADFI = Average Daily Feed Intake; FI = Feed Intake; FCR = Feed Conversion Ratio; WG = Weight Gain; BWG = Body Weight Gain; DWG = Daily Weight Gain; WC = Water Consumption; FC = Feed Consumption; FE = Feed Efficiency;

Heat stress also affected hormonal changes, such as a decrease in thyroid hormones and an increase in corticosterone levels (Miao *et al.*, 2020; Slawinska *et al.*, 2020). In the long term, the impact of heat stress not only reduces chicken performance and feed efficiency but also adversely affects the immune system, carcass quality, and overall welfare of the chickens (Seven *et al.*, 2008; Dai *et al.*, 2011; Alhenaky *et al.*, 2017; Bueno *et al.*, 2020; Lan *et al.*, 2020).

The response of broiler strains to heat stress is not only determined by performance but is also influenced by physiological mechanisms. Heat stress generally increases HSP70 expression in various tissues such as the liver, intestines, spleen, and feathers, which serve as protective markers against cellular protein damage (Hu *et al.*, 2017; Greene *et al.*, 2019). However, to date, there has been no study that directly compares HSP70 expression between strains under the same heat stress conditions. Therefore, claims of specific differences between strains in HSP70 remain speculative.

Thyroid hormone changes in triiodothyronine (T3) and thyroxine (T4) levels exhibit variable patterns. Some studies have reported a decline in T3 and T4 concentrations under chronic heat stress, whereas others observed an increase

Table 3: Meta-analysis results of heat stress effects on broiler performance.

Parameter	Pooled Effect (Estimate)	95 % CI	p-value	I^2 (%)	95 % PI
ADFI (g/bird/day)	-24.873	-26.955; -22.79	< 0.001	84.016	-29.56; -20.19
ADG (g/bird/day)	-19.143	-22.393; -15.89	0.002	16.937	-24.92; -13.37
FCR	0.283	0.121; 0.446	0.011	10.225	0.120; 0.447

Note: CI = Confidence Interval; PI = Prediction Interval; I^2 = percentage of heterogeneity across studies; ADG = Average Daily Gain; ADFI = Average Daily Feed Intake; FCR=Feed Conversion Ratio.

in free T3/T4 fractions as part of a metabolic adaptation (Yalçin *et al*., 2009; Xu *et al*., 2018). A study by Bueno *et al.* (2020) directly compared thyroid hormone levels among strains and found no significant strain-related differences under heat stress; rather, the results were strongly influenced by age. These findings emphasize that most of the variation reported among strains is more likely attributable to age, diet, heat stress protocols, and other non-genetic factors.

Meta analysis

Of the 48 articles systematically reviewed, only a subset met the criteria for inclusion in the statistical analysis. Studies that did not report data or had excessively variable designs were excluded. The meta-analysis results showed that heat stress significantly impacted broiler chicken performance (Table 3). Average daily feed intake (ADFI) decreased by −24.87 g/bird/day (p < 0.001), average daily gain (ADG) decreased by −19.14 g/bird/day (p= 0.002), while the feed conversion ratio (FCR) increased by 0.28 points (p = 0.011). Heat stress disrupts the homeostatic balance of chickens, leading to elevated body temperature, alterations in hormonal regulation, and reduced feed intake (Hu *et al*., 2017; Majdeddin *et al*., 2020).

Heterogeneity analysis (Table 3) showed differences in variation between parameters. Average daily feed intake (ADFI) exhibited high heterogeneity (I^2= 84%), reflecting variability in response to experimental conditions. In contrast, average daily gain (ADG) (I^2= 16.9%) and feed conversion ratio (FCR) (I^2= 10.2%) were relatively consistent across studies.

Table 4: Meta-regression of heat stress effects on broiler performance.

Parameter	Moderators	F	df_1	df_2	p value
ADFI	Strain	0.692	10	3	0.712
	Exposure (Hour)	0.466	6	3	0.544
	Temperature (°C)	0.976	1	3	0.554
ADG	Strain	2.218	9	4	0.230
	Exposure (Hour)	4.861	1	4	0.092
	Temperature (°C)	1.927	5	4	0.272
FCR	Strain	31.39	8	3	0.008
	Exposure (Hour)	452.05	6	3	< 0.001
	Temperature (°C)	10.42	1	3	0.048

Meta-regression analysis (Table 4) demonstrated that strain had a significant effect on FCR (p= 0.008), whereas no significant differences were observed for ADFI (p= 0.712) or ADG (p= 0.230). Moreover, exposure duration (p < 0.001) and temperature (p= 0.048) also significantly influenced FCR. These results suggest that only feed efficiency (FCR) was significantly influenced by genetic background, while variations in ADFI and ADG were not statistically significant and appear to be driven by study heterogeneity and non-genetic factors such as bird age, heat exposure protocols, duration, and nutritional interventions. Therefore, strain comparisons under heat stress should be interpreted with caution, as performance outcomes reflect both genetic and methodological influences (Zhang *et al*., 2017; Lu *et al*., 2019).

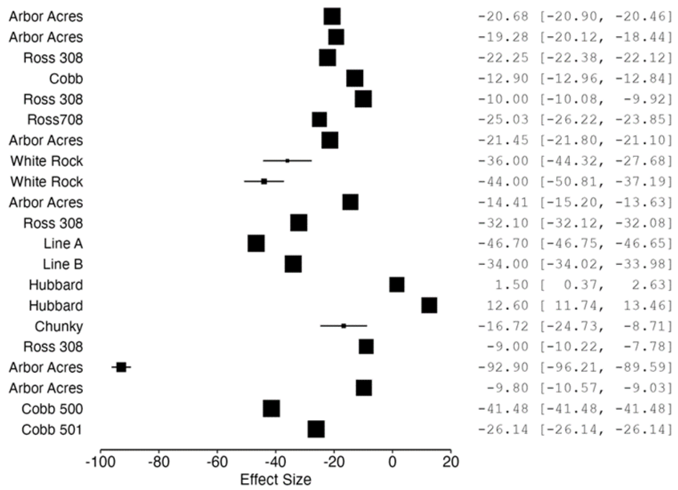

Figure 4: Forest plot of average daily feed intake (ADFI) in different broiler strains under heat stress conditions.

The forest plot results indicate a decrease in ADFI (Figure 4) across all broiler strains when exposed to heat stress. The magnitude of reduction varied, with Ross 708 and Line A exhibiting the greatest declines, whereas Ross 308 showed relatively smaller decreases. Feed intake was consistently reduced under heat stress, although the extent of this reduction was influenced by genetic differences among strains. The decrease in ADG (Figure 5) was also observed under heat stress conditions. Strains such as Arbor Acres and Line A experienced highly significant reductions, while the Hubbard strain showed relatively stable performance, reflecting its greater genetic tolerance to heat stress. An increase in FCR (Figure 6) was particularly evident in Ross

708 and Arbor Acres strains, while Ross 308 and Cobb 500 showed moderate increases, and the Hubbard strain was relatively stable. It indicates that each strain has different variations in susceptibility to heat stress. An increase in FCR can be associated with physiological changes, including increased corticosterone levels and decreased thyroid hormones (He *et al.*, 2019; Yan *et al.*, 2019).

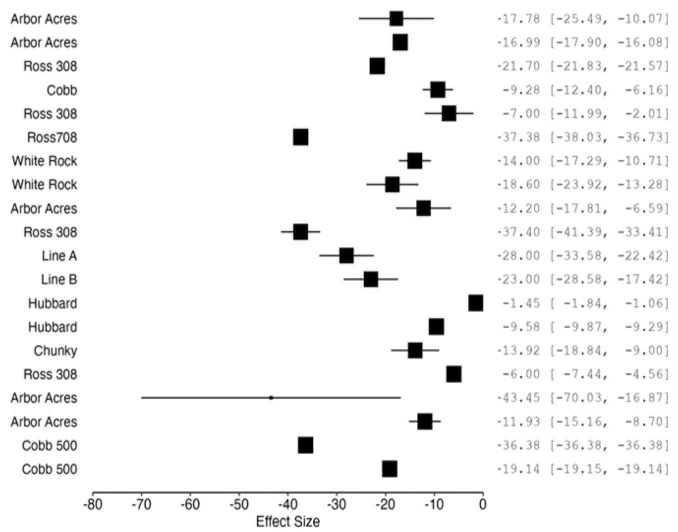

Figure 5: Forest plot of average daily gain (ADG) in different broiler strains under heat stress conditions.

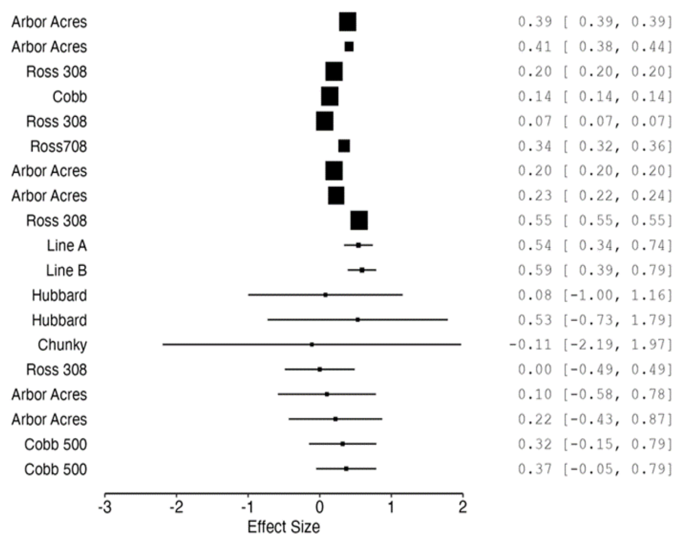

Figure 6: Forest plot of feed conversion ratio (FCR) in different broiler strains under heat stress conditions.

The forest plot results indicated that no single strain demonstrated absolute resistance to heat stress; instead, the degree of tolerance varied depending on the performance parameter assessed. For feed intake (ADFI), Ross 308 showed relatively smaller reductions compared to other strains, whereas Ross 708 and Line A experienced greater declines. Analysis of daily weight gain (ADG) indicated that the Hubbard strain maintained greater stability, whereas Arbor Acres and Line A experienced a significant reduction. Feed conversion ratio (FCR) increased across all strains under heat stress, but the magnitude differed: Ross 708 and Arbor Acres showed the greatest increases, whereas Hubbard remained relatively stable. These findings emphasize that strain-specific responses to heat stress are highly variable and context-dependent, influenced not only by genetic background but also by age, environmental conditions, and experimental design.

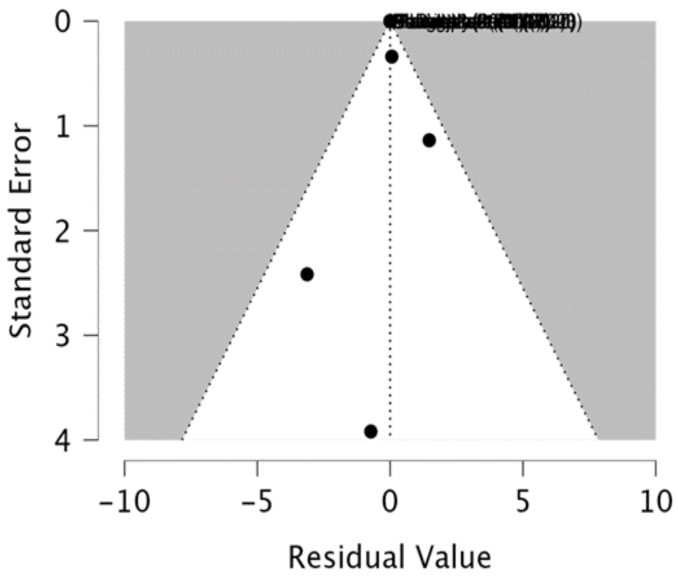

Figure 7: Funnel plot assessing publication bias for average daily gain (ADG) in broiler chickens under heat stress conditions

To verify the reliability of the results, a funnel plot (Figure 7) was used to assess the ADG parameter. The plot showed a symmetrical distribution of studies around the pooled effect line, indicating no evidence of publication bias.

Research scale and sample size

The samples used in each study vary greatly, ranging from 36 to 2400 birds. Studies with large sample sizes usually represent conditions in farms (Heckert *et al.*, 2002). The variation in research samples relates to the research approach and is adjusted to the experimental design according to the objectives to be achieved. The included studies provide insight into heat stress and mitigation strategies that impact chicken performance. Small-scale sample research aims to observe the effects of heat stress on hormones, cell structure, and chicken strains (Bueno *et al.*, 2020; Ma *et al.*, 2019). The results obtained are to understand the mechanisms of performance inside the chicken's body. Small-scale studies are conducted under strict supervision of the environment. Studies with small samples provide in-depth understanding related to biological mechanisms and physiological responses to heat stress (Hu *et al.*, 2017).

Table 5: Effects of heat stress on HSP70 expression and thyroid hormones (T3/T4) in different broiler strains

Author	Strain	HS condition	HSP70 Expression	T3/T4 Hormones
Xu *et al.* (2018)	White recessive rock, lingshan	34 °C (8 h/day for 14 days)	NR	T3 and T4 decreased in Lingshan, stable in White Recessive Rock
Greene *et al.* (2019)	Cobb 500	29.5 °C (Acute 24 h for 21 d)	Significant increase in feathers, blood, and duodenum (mRNA and protein)	NR
Hu *et al.* (2017)	Arbor Acres	35 °C (Chronic 6 h for 10 days)	Significant increase in duodenum, jejunum, and ileum	NR
Yalçin *et al.* (2009)	Ross 308	32 °C (Cyclic 8 h for 20 days)	NR	T3 consistently decreased; T4 showed variable patterns, sometimes increased under HS
He *et al.* (2019b)	Yellow Feather	37 °C (Cyclic 8 h/day for 14 days	Significant increase in HSP70 mRNA	NR
Miao *et al.* (2020)	Arbor Acres	29 °C, 32 °C, 35 °C (Acute 6 h/day for 8 days)	Significant increase in HSP70 mRNA and protein (liver)	NR
Greene *et al.* (2021)	Cobb	35 °C (Cyclic 12 h/day for 21 days)	No significant increase in blood HSP70	NR
Alhotan *et al.* (2021)	Ross 308	33 °C (Cyclic 8h/day h for	Significant increase in HSP70 (jejunum)	NR
He *et al.* (2019c)	Arbor Acres	32 °C (Chronic 24 h/day for 14 days)	NR	HS did not affect T3/T4
Dai *et al.* (2011)	Arbor Acres	30-34 °C (Cyclic, 9 h/day for 21 days)	NR	HS decreased T3 and T4
Bueno *et al.* (2020)	Cobb vs Hubbard Flex	35 °C (Cyclic, 1–3 h/day for 28 days	NR	HS did not directly affect T3/T4; however, T3 decreased with age, while T4 increased at 42 d

Note: NR = Not Reported.

SUGGESTIONS AND RECOMMENDATIONS

Strategies to improve rearing conditions and reduce the impact of heat stress include ventilation management, cooling systems, stocking density, feeding patterns, and genetic selection for heat tolerance. Ventilation plays a role in air circulation and reducing the internal temperature of poultry housing. In addition, cooling systems such as fans and sprayers have been shown to significantly lower ambient temperatures, particularly in tropical regions. Stocking density also requires careful consideration, as higher density increases the heat temperature and effect of heat stress. Besides environmental management, supplementation with vitamin E, glutamine, taurine, and probiotics has been shown to reduce heat stress, increase performance, and increase immunity (El-Deep *et al.*, 2019; Sahin *et al.*, 2017). These approaches, when combined with environmental control, can maintain productivity and animal welfare under hot conditions.

Analysis showed varying strain responses to heat stress across different parameters. Ross 308 showed decreased average daily feed intake (ADFI), while Hubbard maintained relatively stable daily weight gain (ADG) and feed conversion ratio (FCR). While Arbor Acres and Line A were more susceptible, showing greater performance declines, Cobb 500 demonstrated intermediate responses. These findings emphasize that no strain is completely resistant to heat stress. Therefore, it is essential to adapt strains to local conditions, taking into account their availability, production systems, environmental factors, and market demand. Farmers are encouraged to utilize strains that are locally available and support them with appropriate management strategies such as ventilation, cooling, supplementation, and stocking density. These findings should be interpreted as general trends rather than definitive recommendations, with practical strain selection tailored to local availability, production systems, and environmental conditions.

Strategies for reducing heat stress depend on farm scale and resource availability (Renaudeau *et al.*, 2012). Large-scale farms are better positioned to implement modern technologies, including cooling pads, exhaust fans, and specialized feed supplements (Sahin *et al.*, 2017; Yalçin *et al.*, 2003). In contrast, small-scale farms often face financial constraints, making low-cost measures such as natural ventilation, reduced stocking density, provision of shade, and adjusted feeding schedules more practical (Nyoni *et al*., 2019). Consequently, the choice of mitigation strategies depends on local conditions and the production capacity of each farm (Onagbesan *et al*., 2023).

Research gaps and future research

Another limitation of this study is the minimal representation of research from Africa, which may restrict the generalizability of the results to all tropical regions. Future research should prioritize this region, particularly Sub-Saharan Africa, to expand the evidence base and provide a deeper understanding of broiler strain responses to extreme heat conditions.

In addition, one of the shortcomings in this research is the lack of long-term studies evaluating the impact of heat stress throughout the life cycle of broiler chickens. Chronic heat stress can have significant effects on growth, metabolism, and the welfare of the chickens. Furthermore, research related to heat-tolerant strains is still limited. Most studies focus on strains such as Ross and Cobb, while the genetic potential of local strains or crossbreeds that are more heat-resistant has not been extensively explored. Future research directions should focus on genetic selection for heat tolerance, adaptive feed formulation for tropical climates, real-time monitoring of chicken behavior, and the application of artificial intelligence (AI), which holds great potential for more adaptive and sustainable mitigation strategies. This approach can address the increasingly evident challenges of global climate change.

Limitation

This systematic literature review has several limitations. First, variation in study design, environmental conditions, and reporting methods across the analyzed literature may affect the comparability of the results. Second, the limited number of long-term studies and the limited data from certain geographic regions potentially limit the generalizability of the findings. Third, the articles in this systematic review were only written in English, which can cause language bias and exclude important research results that may be published in languages other than English. Finally, although meta-analyses and meta-regressions were performed, considerable heterogeneity in heat stress protocols (temperature, exposure duration, and application pattern) remained. This heterogeneity may explain why FCR showed a significant strain effect, whereas ADFI and ADG showed no significant effect. These findings suggest that strain differences should be interpreted with caution, and further research using standardized protocols and larger datasets is required to strengthen specific comparisons between strains.

CONCLUSION

A systematic review shows that heat stress consistently reduces broiler performance, characterized by decreased feed intake, decreased body weight gain, increased feed conversion, and increased mortality. However, responses differ between strains; only feed conversion ratio (FCR) consistently increased under heat stress conditions, while feed intake (ADFI) and growth (ADG) are more influenced by differences in study heterogeneity and non-genetic factors. These findings emphasize the importance of the interaction between genetics and the environment, as well as the need for adaptive management strategies. Research on local and crossbred strains is still necessary to support sustainable poultry production under climate change.

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NOVELTY STATEMENT

Heat stress remains a major constraint in broiler chicken production. This systematic review highlights strains that are more tolerant to high temperatures and could be prioritized in climate adaptation strategies.

AUTHOR'S CONTRIBUTION

AFN: Designed the manuscript and wrote the manuscript.
MM: Contributed to revising the manuscript and approved the final manuscript.

Generative AI and AI-assisted technology statement

The authors declare that generative artificial intelligence (AI) tools, including ChatGPT (OpenAI) and QuillBot, were used in a limited capacity to improve grammatical accuracy, linguistic clarity, manuscript quality, and to assist in refining the interpretation of the study's findings. All data analyses, scientific reasoning, interpretations, and final revisions were conducted and fully verified by the authors, who take full responsibility for the integrity and accuracy of the manuscript's content.

Conflict of interest

The authors have declared no conflict of interest.

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