JWPR
Journal of World's Poultry Research
2025, Scienceline Publication
J. World Poult. Res. 15(1): 65-73, 2025
Research Paper
DOI: https://dx.doi.org/10.36380/jwpr.2025.6
PII: S2322455X2500006-15
ISSN: 2322-455X

Broiler Farming in the Face of Accelerating Climate Change: Risks for Production and Food Security

Abdelhak Karim Mouss[1]*, Dalila Hammouche[1], and Rahla Meziane[2]

[1]*Faculty of Nature and Life Sciences and Earth Sciences, Djilali Bounaama University, Road to Theniet El Had, Khemis Miliana - Ain Defla, 44225, Algeria*
[2]*Department of Veterinary Sciences, Institute of Veterinary Sciences and Agricultural Sciences, University of Batna 1- Hadj Lakhdar, The aisles of May 19 Road to Biskra, Batna, 05000, Algeria*

*Corresponding author's E-mail: a.mouss@univ-dbkm.dz

Received: December 16, 2024, Revised: January 19, 2024, Accepted: February 08, 2025, Published: March 30, 2025

ABSTRACT

Climate change poses significant challenges to poultry farming, particularly when broiler farms rear chickens in suboptimal housing conditions. The objective of the present study was to examine the impact of climate change, expressed through the Temperature Humidity Index (THI), on quantitative (carcass yields, pectoral muscles, thighs and drumsticks, and abdominal fat rate) and qualitative production parameters (composition of muscles in dry matter, mineral matter, crude proteins, and fat). The study was conducted in two separate poultry buildings over 45 days in northern Algeria. A total of 300 one-day-old unsexed chicks were randomly allocated into three replicates of 50 broilers each per building. The conditions of temperature and relative humidity were strictly regulated in control group but it was unregulated, exposing birds to natural climate variations in the experimental group. The impact of climate change, represented by the Temperature Humidity Index (THI), on carcass yield, pectoralis major and minor (pectoral muscles), sartorius and gastrocnemius (thigh and drumstick muscles), as well as abdominal fat content were evaluated. The results revealed that the control group was exposed to THIs of 30.88, 20.45, and 19.19, while the experimental group was subjected to THIs of 33.07, 31.48, and 30.87 for the three growth phases. The increase in THI resulted in significant proportional deteriorations in the experimental group compared to the control group, for all the parameters under study, particularly at the end of breeding. There were reductions in yields of -6.12% for eviscerated carcasses, -8.16% for thighs and drumsticks, and -9.28% for pectoral muscles. Furthermore, the abdominal fat rate increased by +21.03%. The nutritional composition of pectoral muscles showed that chickens in the experimental group had +6.17% dry matter, +13.23% fat, -13.88% mineral matter, and -8.78% crude proteins. A similar trend was observed for thigh and drumstick muscles, with +6.10% dry matter, +14.39% fat, -12.28% mineral matter, and -12.50% crude proteins. The study highlighted the impact of climate change on poultry farming, which potentially affects production and threatens food security.

Keywords: Broiler chicken, Carcass, Climate change, Food security, Muscle, Nutritional quality, Yield

INTRODUCTION

The poultry sector, encompassing its two main branches of meat and egg production, plays a vital role in global human nutrition by providing animal-based proteins, notably meat and eggs. Poultry products, particularly meat and eggs, are widely consumed across diverse populations, especially in emerging economies where they serve as a critical dietary staple. According to data from FAOSTAT (2023), poultry meat accounts for approximately 33% of global meat production, underscoring the sector's critical contribution to protein intake for humans. With the global population projected to reach 9.9 billion by 2050 (PRB, 2020), including an additional one billion people in Africa alone (Thornton et al., 2009), demand for poultry products is expected to rise systematically. Projections indicate a 70% increase during this period (Searchinger et al., 2019). To meet this growing demand, fast-growing chickens, developed through over 70 years of genetic advancements, have significantly improved feed efficiency and production (Zuidhof et al., 2014; Tallentire et al., 2018). However, these advances have also accelerated metabolism, increasing metabolic heat production while leaving broiler chickens with underdeveloped

cardiovascular and respiratory systems. This combination renders them less thermotolerant and more susceptible to heat stress (Lu et al., 2007; Xu et al., 2018). Unlike mammals, broiler chickens lack sweat glands, relying instead on a thermoregulatory system that balances heat production and dissipation (Kumar et al., 2021). When this balance is disrupted, thermal stress ensues, leading to hyperthermia (Renaudeau et al., 2012; Rostagno, 2020). Hyperthermia is primarily characterized by an increased respiratory rate and significant loss of carbon dioxide to the environment.

Meanwhile, climate change, characterized by extreme deviations in climate patterns over extended periods (Ngaira, 2007), is expected to intensify further. Projections indicate that by 2050, climate patterns will include prolonged heatwaves, reduced rainfall, and overall atmospheric warming, particularly in equatorial, tropical, and Mediterranean regions (IPCC, 2018). These changes pose significant threats to agricultural and socio-economic development, with animal production systems being particularly vulnerable. Similarly, Surai and Fisinin (2016) reported that industrial poultry farming faces multiple stressors, including heat stress, adversely affecting production, reproduction performance, and overall poultry health. Attia et al. (2022) emphasized that emerging countries, particularly in Africa, are especially vulnerable to climate change due to inadequate infrastructure. As noted by Attia et al. (2022), poultry housing in these regions often fails to meet environmental standards, lacking proper insulation and climate control systems. Such conditions negatively impact the development and sustainability of poultry activities.

Findings indicate that high ambient temperatures induce heat stress, adversely affecting poultry farming, particularly broiler chickens (Lara and Rostagno, 2013). Thermal stress can be acute, characterized by a sudden temperature increase over a short period. Furthermore, it is classified as chronic when it persists over an extended period (Nawaz et al., 2021). Regardless of the type of stress, chain reactions are triggered in broiler chickens, which, in some instances, deteriorate carcass appearance and nutritional quality (Qu and Ajuwon, 2018; Zhao et al., 2019; Zhang et al., 2020), potentially compromising the availability of poultry products and, consequently, food security.

Given these considerations, the present study examines the impact of climate change, expressed through the Temperature Humidity Index (THI), on both quantitative and qualitative production parameters in Cobb 500 broiler chickens raised during the summer season.

MATERIALS AND METHODS

Ethical approval

The study was approved by the Faculty of Nature and Life Sciences and Earth Sciences at Djilali Bounaama University of Khemis Miliana. It was conducted over a period of forty-five days, from July 15 to August 30, 2023.

Methodological approach

The experimental study evaluated the impact of climate change, represented by the Temperature Humidity Index (THI), on carcass yield, pectoralis major and minor (pectoral muscles), sartorius and gastrocnemius (thigh and drumstick muscles), as well as abdominal fat content. Furthermore, the composition of significant nutrients was analyzed in the muscles used to measure yields and included the rate of dry matter, mineral matter, crude proteins, and fat. The study was conducted in two separate buildings during summer, lasting forty-five days between July 15th and August 30th, 2023. A total of 300 unsexed chicks from the Cobb 500 strain were received at one day of age (150 per building), and further divided into three random replicates, each with 50 broilers. The first building was modern, climate-controlled, and served as the control group (group C). The temperature was recorded as 32.95 ± 2.47, 21.14 ± 2.98, and 19.67 ± 1.81°C, and the relative humidity as 64.01 ± 2.56, 67.19 ± 4.83, and 69.44±4.75%, for the starter, grower, and finisher phases, respectively. In contrast, the second building was less equipped, had an uncontrolled environment, and was subject to natural climate variations, representing the experimental group (group E). The temperature in this building was 35.93 ± 1.77, 33.93 ± 2.63, and 33.44 ± 1.76°C, and the humidity was 57.21 ± 3.73, 59.57 ± 7.09, and 56.42 ± 2.62%, for the same breeding phases. Furthermore, parameters were analyzed during the starter, grower, and finisher phases at the fifteenth, thirtieth, and forty-fifth breeding days. Finally, broiler chickens were fed an identical commercial standard diet at each growth phase throughout the study. The composition and chemical analysis of these diets are reported in Table 1.

A standard lighting program was followed during the study. Lamps provided light, ensuring an approximate intensity of 5 watts/m². In addition, twenty-three hours of lighting were provided during the first week. From the 8th day of age onwards, a lighting duration of between eighteen and nineteen hours was maintained. For its part, vaccination procedures were standardized. Broilers were vaccinated against Newcastle and Gumboro diseases on the 8th and 18th days of age. On the day 23, vaccination

against coccidiosis was administered. Finally on day 29 coincided with a booster vaccination against Newcastle disease.

Table 1. Composition and chemical analysis of diet for the different growth phases

Composition (%)	Starter	Grower	Finisher
Maize	61	65	68
Soybean meal	27.5	24.3	21
Wheat bran	6	5.5	5.9
Calcium carbonate	2.7	2.7	2.7
Dicalcium phosphate	1.9	1.6	1.5
Mineral and vitamin premix	0.3	0.3	0.3
NaCl	0.3	0.3	0.3
L-lysine	0.1	0.1	0.1
DL-methionine	0.1	0.1	0.1
L-threonine	0.1	0.1	0.1
Chemical analysis			
Metabolizable energy (kcal/kg)	2900	2900	2950
Crude proteins (%)	21	19	17
Fat (%)	2.5	2.5	2.5
Crude fiber (%)	4	4	4
Lysine (%)	0.88	0.88	0.80
Methionine (%)	0.38	0.36	0.36
Calcium (%)	0.8	0.8	0.8
Phosphorus (%)	0.7	0.7	0.7

Methods for measuring ambient parameters

Ambient temperature and relative humidity were measured using Kimo KH 50 recording thermo-hygrometers manufactured by Testoon, France. These devices were placed at the center and both ends of the breeding buildings and recorded data every 30 minutes.

Method for measuring Temperature Humidity Index

The Temperature Humidity Index (THI) was calculated using the formula proposed by Marai et al. (2000).

$$THI = T- [(0.31 – 0.31xRH/100) (T-14.4)] \text{ (Formula 1)}$$

THI: Temperature Humidity Index, T: Temperature (°C), and RH: Relative Humidity (%).

Methods for measuring carcass yields

At 15, 30, and 45 days of age, 10 broiler chickens were selected based on an average live weight representative of each group. The live weights in the control group were 592.98 ± 39.00, 1827.13 ± 99.48, and 2926.64 ± 129.25g on days 15, 30, and 45, respectively. In the experimental group, the corresponding weights were 460.85 ± 31.01, 1521.92 ± 93.01, and 2165.90 ± 115.11g. The evaluated yields included eviscerated carcasses, thighs and drumsticks, pectoral muscles, and abdominal fat. To this end, after fasting for twelve hours, each chicken was slaughtered by bleeding the carotid artery and jugular vein. Following bleeding, the chickens were immersed in water at an average temperature of 60°C for two minutes to facilitate plucking, following the recommendations of Faria et al. (2010). Furthermore, the dissection of carcasses was performed according to the standard method described by Jensen (1984). After removing the head and legs, the carcasses were placed in dorsal decubitus on dissection trays. An abdominal opening was made using a scalpel blade, allowing the abdominal cavity to be lifted and folded forward. Abdominal fat, the digestive tract, and the giblets were removed. The eviscerated carcasses were weighed using Dawood brand electronic scales manufactured by Dongyang Zhibo Weighing Scales Factory, China. The yield of eviscerated carcasses was measured according to the following formula:

$$\text{Carcass yield (\%)} = \frac{\text{Eviscerated carcass weight (g)}}{\text{Slaughter weight (g)}} \times 100 \text{ (Formula 2)}$$

Isolation of the lower limbs of the carcasses was carried out by folding the pair of thighs until they were disarticulated from the pelvis. A horizontal incision was made to detach the pair of legs from the rest of the carcass. Additionally, the skin and fat covering the pectoral muscles were removed. An incision was made along the sternum and collarbones, allowing the pectoral muscles to be removed from the rib cage. The pair of legs, as well as the pectoral muscles, were weighed using the same scale. The yields of these cuts were calculated using the following formula:

$$\text{Cutting yield (\%)} = \frac{\text{Cutting weight (g)}}{\text{Slaughter weight (g)}} \times 100 \quad \text{(Formula 3)}$$

Abdominal fat was also weighed using the same scale and its proportion was calculated as follows:

$$\text{Fat proportion (\%)} = \frac{\text{Abdominal fat weight (g)}}{\text{Slaughter weight (g)}} \times 100 \text{ (Formula 4)}$$

Finally, after measuring the yields, samples of thigh and drumstick muscles and pectoral muscles were collected from each sample. They were stored at -18°C for subsequent determination of nutritional composition.

Methods for measuring the nutritional quality of muscles

Ten samples of thigh, drumstick, and pectoral muscles were thawed at room temperature. They were crushed and subjected to chemical analyses to determine their nutritional composition. Each analysis was carried out in triplicate for each sample. The analyses followed AOAC (2000) recommendations. Dry matter (DM%) was determined by drying a muscle sample in an oven manufactured by Memmert, Germany, for 24 hours at an average temperature of 105°C. Mineral matter (MM%) was determined by calcining a muscle sample in an incinerator manufactured by Nabertherm, Germany, for 1.5 hours at 200°C, followed by 2.5 hours at 500°C. The percentage of crude proteins (CP%) was measured after mineralizing a muscle sample using the Kjeldahl device manufactured by Buchi, Switzerland. The sample was mineralized with sulfuric acid in the presence of a catalyst; the organic nitrogen was transformed into ammoniacal nitrogen, and the ammonia was displaced by sodium hydroxide and measured after being absorbed in a boric acid solution. Finally, ethereal extract (EE%) was determined using Soxhlet extraction columns manufactured by Gerhardt, Germany. An organic solvent (diethyl ether) and anhydrous sodium sulfate catalyst were used to carry out this analysis.

Data analysis

The results of all measurements were expressed as means ± standard deviations, and calculations were carried out using Microsoft Excel software, version 2007. Data analysis was carried out using the same software, which performed a one-way analysis of variance (ANOVA 1) using Student's t-test. The significance level was set at $p < 0.05$, $p < 0.01$, and $p < 0.001$.

RESULTS

Ambient parameters

The ambient parameters revealed that the control group was reared under lower temperatures and higher humidity than those recorded in the experimental group, particularly during the grower and finisher phases (Table 2). Indeed, the ambient temperatures were established at 32.95 ± 2.47, 21.14±2.98, and 19.67 ± 1.81°C, respectively, for the three breeding phases in the control group. Furthermore, the temperatures were higher in the experimental group, where they were established, respectively, for the three growth phases at 35.93 ± 1.77, 33.93±2.63, and 33.44±1.76°C. The relative humidity was, on average, 64.01 ± 2.56, 67.19 ± 4.83, and 69.44 ± 4.75% during the three rearing phases in the control group. This atmospheric component was much lower in the experimental group, where the averages of 57.21 ± 3.73, 59.57 ± 7.09, and 56.42 ± 2.62% were noted.

Table 2. Ambient parameters during the study in Ain Defla, Algeria at summer 2023

	Temperature (°C)		Relative humidity (%)	
	Group C	Group E	Group C	Group E
Starter	32.95±2.47	35.93±1.77	64.01±2.56	57.21±3.73
Grower	21.14±2.98	33.93±2.63	67.19±4.83	59.57±7.09
Finisher	19.67±1.81	33.44±1.76	69.44±4.75	56.42±2.62

C: Control; E: Experimental.

Temperature humidity indexes

The temperature humidity indexes were higher in the experimental group than in the control group, regardless of the breeding phase (Table 3). Indeed, in the experimental group, these values were 33.07, 31.48, and 30.87 for the starter, grower, and finisher phases, respectively. On the other hand, they were established at 30.88, 20.45, and 19.17, respectively, for the same breeding phases in the control group.

Table 3. Temperature humidity indexes during the study in Ain Defla, Algeria at summer 2023

	Temperature humidity indexes	
	Group C	Group E
Starter	30.88	33.07
Grower	20.45	31.48
Finisher	19.17	30.87

C: Control; E: Experimental.

Carcass yields

The evolution of carcass yields revealed notable reductions in the experimental group compared to the control group (Table 4) at different sampling ages. Regarding the eviscerated carcass, a significant decrease was observed in the starter phase on the 15th day of age (-2.31%; $p < 0.01$). In the growth phase, the reduction was significantly minimal (-0.89%) on the 30th day. In contrast, a significant ($p < 0.001$) decrease was observed in the finisher phase on the 45th day, reaching -6.12%. Regarding the yields of thighs and drumsticks, during the starter phase, a non-significant decrease (-3.53%) was noted on the 15th day. In the grower and finisher phases, significant reductions were pointed out on the 30th day (-7.87%; $p < 0.01$) and the 45th day (-8.16%; $p < 0.001$). As for the pectoral muscles, the reduction in yield was significant (-9.39%; $p < 0.001$) from the first sampling in the starter

phase. However, this drop was less in the second sampling (-5.77%) and was not statistically significant. Furthermore, at the last sampling, a considerable decrease was observed (-9.28%; $p < 0.001$). Finally, the abdominal fat percentage revealed significant increases in broiler chickens of the experimental group compared to those of the control group, where increases of +10.81%, +12.15%; $p < 0.01$, and +21.03%; $p < 0.001$ were observed at the 15th, 30th, and 45th days of age.

Nutritional composition of the pectoral muscles

The overall trend of the results indicated that the pectoral muscles of broiler chickens in the experimental group exhibited higher dry matter and fat content, along with lower levels of mineral matter and crude proteins, compared to the control group (Table 5). Indeed, in the starter phase, dry matter showed a non-significant increase of +1.35% in terms of proportion, noted on the 15th day of age. Furthermore, in the grower and finisher phases, significant increases of +4.45% ($p < 0.05$), and +6.17% ($p < 0.01$) were observed on the 30th and 45th days. Regarding the mineral matter, in the starter and grower phases, significant decreases ($p < 0.05$) were observed on the 15th and 30th days, respectively at -10.27%, and -12.51%. The decrease was more marked in the finisher phase, reaching -13.88% on the 45th day. Similarly, crude protein levels followed a declining trend, with a significant decrease of 6.33% ($p < 0.01$) observed in the starter phase on the 15th day. The decrease was also substantial in the grower phase and stood at -7.18%; $p < 0.05$ on the 30th day, while in the finisher phase, a statistically significant decline of 8.78% ($p < 0.01$) was noted on the 45th day. Finally, the pectoral muscles contained more fat in the broiler chickens of the experimental group compared to those of the control group. Statistically significant increases ($p < 0.01$) were recorded in the starter and grower phases, reaching +6.35% and +10.48% on the 15th and 30th days of age, respectively. This increase was more significant in the finisher phase and stood at +13.23%; $p < 0.001$ on the 45th day.

Table 4. Carcass yields (%) during the study in Ain Defla, Algeria at summer 2023

	Eviscerated carcass	Thighs and drumsticks	Pectoral muscles	Abdominal fat
		D 15		
Group C	62.35±0.89^{a}	16.69±0.74^{a}	18.05±0.62^{a}	0.99±0.08^{a}
Group E	60.94±1,20^{b}	16.12±0,55^{a}	16.50±0.84^{b}	1.11±0.09^{b}
P-value	0.0081	> 0.05	0.00019	0.0043
		D 30		
Group C	65.53±1,07^{a}	18.78±0,86^{a}	19.26±1,26^{a}	1.59±0.14^{a}
Group E	64.95±0,77^{a}	17.41±0,69^{b}	18.21±1,09^{a}	1.81±0.18^{b}
P-value	>0.05	0.0010	> 0.05	0.0091
		D 45		
Group C	70.37±2.03^{a}	22.53±0.57^{a}	23.20±0.90^{a}	1.99±0.11^{a}
Group E	66.31±1.70^{b}	20.83±0.95^{b}	21.23±1.17^{b}	2.52±0.33^{b}
P-value	0.00013	0.00012	0.00052	0.00017

^{a,b} Means with different superscript letters in the same column represent significant differences at $p < 0.05$; C: Control; D: Day; E: Experimental.

Table 5. Nutritional quality of pectoral muscles during the study in Ain Defla, Algeria at summer 2023

	DM (%)	MM (%DM)	PB (%DM)	EE (%DM)
		D 15		
Group C	24.74±1.46^{a}	8.05±0,65^{a}	18.13±0.74^{a}	6.93±0.38^{a}
Group E	25.08±1.72^{a}	7.30±0.71^{b}	17.05±0.80^{b}	7.40±0.67^{b}
P-value	>0.05	0.024	0.0058	0.0091
		D 30		
Group C	26.85±1.27^{a}	7.73±0.56^{a}	19.41±1.21^{a}	9.05±0.78^{a}
Group E	28.10±0,71^{b}	6.87±0.86^{b}	18.11±1.13^{b}	10.11±0.66^{b}
P-value	0.014	0.016	0.022	0.0042
		D 45		
Group C	27.22±1.14^{a}	8.53±0.52^{a}	18.45±0.97^{a}	10.10±0.64^{a}
Group E	29.01±1.19^{b}	7.49±0.46^{b}	16.96±1.14^{b}	11.64±0.93^{b}
P-value	0.0029	0.00017	0.0055	0.00044

^{a,b} Means with different superscript letters in the same column represent significant differences at $p < 0.05$; C: Control; CP: Crude Proteins; D: Day; DM: Dry Matter; E: Experimental; EE: Ethereal Extract; MM: Mineral Matter.

Nutritional composition of thigh and drumstick muscles

The evolution of the nutritional composition of the thigh and drumstick muscles showed similarities with that of the pectoral muscles, where the broiler chickens in the experimental group contained more dry and fatty matter and less protein and minerals compared to those in the control group (Table 6). During the starter, grower, and finisher phases, dry matter content demonstrated statistically significant increases, recorded at +5.66% ($p < 0.05$) on the 15th day, +6.54% ($p < 0.01$) on the 30th day, and +6.10% ($p < 0.001$) on the 45th day of age. Mineral matter revealed a significant decrease (-7.77%; $p < 0.05$) in the starter phase on the 15th day. This was -9.84% in the grower phase, statistically insignificant on the 30th day. On the other hand, the decrease was significant in the finisher phase and revealed an amplitude of -12.28% ($p < 0.01$) on the 45th day. Crude protein levels exhibited notable decreases across all growth phases, with reductions of -11.69% ($p < 0.001$) on the 15th day, -8.54% ($p < 0.05$) on the 30th day, and -12.50% ($p < 0.001$) on the 45th day. The fat level was higher in broiler chickens in the experimental group than those in the control group. Non-significant increases were noted during the starter and grower phases, recorded at +10.05% and +12.87% on the 15th and 30th days of age, respectively. Furthermore, a significantly greater increase was observed in the finisher phase on the 45th day, when it reached +14.39%; $p < 0.001$.

Table 6. Nutritional quality of the thigh and drumstick muscles during the study in Ain Defla, Algeria at summer 2023

	DM (%)	MM (%DM)	PB (%DM)	EE (%DM)
		D15		
Group C	26.14±1.45^{a}	4.84±0.60^{a}	10.96±0.73^{a}	17.57±0.67^{a}
Group E	27.71±1.60^{b}	4.49±0.76^{b}	9.81±0.45^{b}	19.53±0.61^{a}
P-value	0.034	0.028	0.00053	>0.05
		D 30		
Group C	27.91±1.30^{a}	5.70±0.78^{a}	13.46±0.97^{a}	18.42±0.70^{a}
Group E	29.86±1.28^{b}	5.19±0.38^{a}	12.41±0.84^{b}	21.14±0.84^{a}
P-value	0.0033	> 0.05	0.017	> 0.05
		D45		
Group C	29.01±0.78^{a}	6.33±0,54^{a}	13.84±0.76^{a}	19.86±1.28^{a}
Group E	30.89±1.10^{b}	5.64±0.39^{b}	12.30±0.85^{b}	23.20±2.03^{b}
P-value	0.00033	0.0040	0.00048	0.00036

^{a,b} Means with different superscript letters in the same column represent significant differences at $p < 0.05$; C: Control; CP: Crude Proteins; D: Day; DM: Dry Matter; E: Experimental; EE: Ethereal Extract; MM: Mineral Matter.

DISCUSSION

Ambient conditions and temperature humidity indexes

This study aimed to investigate the potential impacts of climate change on broiler farming, as reflected through the Temperature Humidity Index (THI), and to assess its consequences on both quantitative and qualitative aspects of production. The experimental conditions exposed the broiler chickens in the experimental group to thermal stress. The breeding guide for the Cobb 500 (2008) recommends a reception temperature for broilers of 33°C. This temperature gradually lowers by 2 to 3°C every three days and eventually maintains between 18 and 20°C from the fourth week of age until marketing. In addition, the increase in temperature has also led to a drying of the atmosphere, as evidenced by the relative humidity values observed (less than 60% for the three breeding phases). In contrast, the same breeding guide suggests that the relative humidity values should be approximately 70%. Furthermore, the measurement of THI revealed that it exceeded 30 in the experimental group, regardless of the breeding phase considered. These findings confirm the presence of thermal stress, as classified by Duduyemi and Oseni (2012), who categorized THI into three levels, including values below 26 as the limit zone of comfort, values between 26 and 29 as the heat stress zone, and values exceeding 29 as the severe heat stress zone. Additionally, Kang et al. (2020) emphasized the applicability of the THI as a tool for assessing the effects of heat stress in poultry farming.

Carcass yields

The environmental conditions of the experiment, expressed through the Temperature Humidity Index, strongly impacted different yields. This was reflected in a reduction in carcass yield and major cuts, and an increase in the proportion of abdominal fat. Similar trends have been reported in previous studies, which have reported that heat stress situations induce a reduction in the yield of

eviscerated carcasses (Al-Sultan et al., 2019; Liu et al., 2019; Moustafa et al., 2021), in thighs and drumsticks (Shao et al., 2019; Moustafa et al., 2021), as well as in chest muscles (Zeferino et al., 2016; Cramer et al., 2018; Omran et al., 2020). In addition, an increase in the proportion of abdominal fat under heat stress conditions has been documented by Habibian et al. (2016), Zeferino et al. (2016), and Al-Sultan et al. (2019). To explain these findings, Zhang et al. (2012) suggested that reduced carcass yields could be associated with undesirable meat attributes, particularly in fast-growing poultry. Furthermore, Song et al. (2018) and Zaboli et al. (2019) suggested that the increase in abdominal fat could be linked to hormonal imbalances, particularly hypercorticosteronemia, which would slow down the protein synthesis process. Zhang et al. (2012) further postulated that excessive fat accumulation results from a decline in basal metabolism and physical activity, which would follow hypothyroidism. In addition, Lu et al. (2007) deduced that the impact of heat stress would be directly linked to ambient temperature rather than solely by a reduction in feed intake. Finally, Zhang et al. (2012) and Bayu et al. (2016) reported that fat accumulation leads to the degradation of carcass appearance and yields, which would have significant consequences on production and economic profits (Zhang et al., 2012).

Nutritional composition of muscles

The results demonstrated that broiler chickens in the experimental group experienced a deterioration in nutritional quality, which resulted in an increase in the dry and fat matter and a decrease in mineral matter and crude proteins, irrespective of the muscle type considered. These findings align with previous studies that reported similar deteriorations in carcass nutritional quality when rearing temperature exceeded the required standards. Indeed, under these stressful conditions, Attia and Hassan (2017) noted an increase in dry matter and a decrease in muscle mineral matter. For their part, Shao et al. (2019) observed a reduction in crude protein levels. Furthermore, Zhang et al. (2012) and De Antonio et al. (2017) noted an increase in the proportion of muscle fat. The deterioration in nutritional quality observed under thermal stress would result from the stimulation of the hypothalamic-pituitary-adrenal axis, which increased serum corticosterone concentration (Sapolsky et al., 2000). High levels of this hormone impact lipid metabolism by inhibiting the action of hormone-sensitive lipase, thus promoting hepatic lipogenesis (Vasilatos-Younken, 1995; Hausman et al., 2012), which leads to the storage of fats in adipocytes and the reduced release of free fatty acids into the bloodstream, causing fat accumulation in the abdomen, neck, and thighs (Cai et al., 2009; Wang et al., 2012 a; b). In addition, hypercorticosteronemia stimulated insulin production, a potent lipoprotein lipase activator, thus promoting muscle protein catabolism (Scanes, 2016). Collectively, the findings of this study suggested that thermal stress, driven by climate change and expressed through the Temperature Humidity Index, could profoundly affect protein and lipid metabolism, thereby deteriorating carcass yields and degrading nutritional quality.

CONCLUSION

Climate change, as reflected by the Temperature Humidity Index (THI), has had a direct impact on broiler farming, leading to declines in both production yields and carcass nutritional quality. Ultimately, this could negatively impact the entire realm of production and, consequently, the availability of products, the sustainability of the activity, and food security, given the role poultry products play in feeding populations. The present results underscored the importance of further research into the impact of heat stress in poultry farming in general and in broiler farming in particular. This would make it possible to conceptualize strategies to combat the harmful effects of heat stress, ensuring a balance between production efficiency and the long-term sustainability of the industry.

DECLARATIONS

Funding

This study was funded by the Faculty of Nature and Life Sciences and Earth Sciences, Djilali Bounaama University of Khemis Miliana, Algeria.

Acknowledgments

The authors warmly thank the poultry farmers for granting access to their facilities and for their cooperation in implementing the experimental protocol.

Availability of data and materials

The datasets generated and analyzed during the current study are available from the corresponding author and the first author upon reasonable request.

Competing interests

The authors declare no conflicts of interest.

Authors' contributions

Abdelhak Karim Mouss played a key role in designing the study, conducting the experiment, collecting samples, measuring yields, performing laboratory

analyses, carrying out statistical analyses, drafting the manuscript, and making revisions. Dalila Hammouche participated in the study's design, followed the statistical analysis, supervised the analyses in the laboratory, and contributed to manuscript revisions. Rahla Meziane assisted in drafting the manuscript. All authors read and approved the final manuscript.

Ethical considerations

All authors were screened for ethical issues, including plagiarism, consent for publication, misconduct, fabrication of data, and duplicate publication or submission.

REFERENCES

Al-Sultan SI, Abdel-Raheem SM, Abd-Allah SMS, and Edris AM (2019). Alleviation of chronic heat stress in broilers by dietary supplementation of novel feed additive combinations. Slovenian Veterinary Research, 56(Suppl 22): 269-279. DOI: https://www.doi.org/10.26873/SVR-766-2019

Association of official analytical chemists (AOAC) (2000). Official methods of analysis, 17th Edition. Gaithersburg, M.D. Available at: http://hdl.handle.net/10637/3158

Attia YA and Hassan SS (2017). Broiler tolerance to heat stress at various dietary protein/energy levels. European Poultry Science, 81: 1-15. DOI: https://www.doi.org/10.1399/eps.2017.171

Attia YA, Rahman MT, Hossain MJ, Basiouni S, Khafaga AF, Shehata AA, and Hafez HM (2022). Poultry production and sustainability in developing countries under the COVID-19 crisis: Lessons learned. Animals, 12(5): 644. DOI: https://www.doi.org/10.3390/ani12050644

Bayu AN, Rudi A, Sri D, and Tuti S (2016). Stress indicator, carcass composition, and meat cholesterol of kampung-broiler crossbred chicken treated by different stocking density. Animal Production, 18(3): 149-156. DOI: https://www.doi.org/10.20884/1.jap.2016.18.3.575

Cai Y, Song Z, Zhang X, Wang X, Jiao H, and Lin H (2009). Increased de novo lipogenesis in liver contributes to the augmented fat deposition in dexamethasone-exposed broiler chickens (*Gallus gallusdomesticus*). Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, 150(2): 164-169. DOI: https://www.doi.org/10.1016/j.cbpc.2009.04.005

COBB 500 (2008). The cobb broiler breeding guide. Cobb-Vantress Incorporated. Arkansas U.S., pp. 1-70. Available at: https://v-assets.cdnsw.com/fs/Root/6q4ag-Inconnu_Layout_1.pdf

Cramer T, Kim H, Chao Y, Wang W, Cheng H, and Kim Y (2018). Effects of probiotic (*Bacillus subtilis*) supplementation on meat quality characteristics of breast muscle from broilers exposed to chronic heat stress. Poultry Science, 97(9): 3358-3368. DOI: https://www.doi.org/10.3382/ps/pey176

De Antonio J, Fernandez-Alarcon MF, Lunedo R, Squassoni GH, Ferraz ALJ, Macari M, Furlan RL, and Furlan LR (2017). Chronic heat stress and feed restriction affects carcass composition and the expression of genes involved in the control of fat deposition in broilers. Journal of Agricultural Science, 155(9): 1487-1496. DOI: https://www.doi.org/10.1017/S0021859617000624

Duduyemi OA and Oseni SE (2012). Modelling heat stress characteristics on layers' performance traits in southwestern Nigeria. Tropentag, Germany. Available at: https://www.tropentag.de/2012/abstract.php?code=u9eriHLA

Faria PB, Bressan MC, De Souza XR, Rossato LV, Botega LMG, and Gama L (2010). Carcass and parts yield of broilers reared under a semi-extensive system. Brazilian Journal of Poultry Science, 12(3): 153-159. DOI: https://www.doi.org/10.1590/S1516-635X2010000300003

Food and agriculture organization of the United Nations (FAOSTAT) (2023). World food and agriculture, statistical yearbook. Rome, pp. 13-27. DOI: https://www.doi.org/10.4060/cc8166en

Habibian M, Ghazi S, and Moeini MM (2016). Effects of dietary selenium and vitamin E on growth performance, meat yield, and selenium content and lipid oxidation of breast meat of broilers reared under heat stress. Biological Trace Element Research, 169(1): 142-152. DOI: https://www.doi.org/10.1007/s12011-015-0404-6

Hausman GJ, Barb CR, Fairchild BD, Gamble J, and Lee-Rutherford L (2012). Expression of genes for interleukins, neuropeptides, growth hormone receptor, and leptin receptor in adipose tissue from growing broiler chickens. Domestic Animal Endocrinology, 43(3): 260-263. DOI: https://www.doi.org/10.1016/j.domaniend.2012.03.008

Intergovernmental panel on climate change (IPCC) (2018). Global warming of 1.5°C. Working group I technical support unit. Switzerland, pp. 1-32. Available at: https://www.ipcc.ch/sr15/

Jensen JF (1983). Method of dissection of broiler carcasses and description of parts. Papworth's Pendragon Press, Cambridge, United Kingdom.

Kang S, Kim DH, Lee S, Lee T, Lee KW, Chang HH, Moon B, Ayasan T, and Choi YH (2020). An acute, rather than progressive, increase in temperature-humidity index has severe effects on mortality in laying hens. Frontiers in Veterinary Science, 7: 568093. DOI: https://www.doi.org/10.3389/fvets.2020.568093

Kumar M, Ratwan P, Dahiya SP, and Kumar Nehra A (2021). Climate change and heat stress: Impact on production, reproduction and growth performance of poultry and its mitigation using genetic strategies. Journal of Thermal Biology, 97(2): 102867. DOI: https://www.doi.org/10.1016/j.jtherbio.2021.102867

Lara LJ and Rostagno MH (2013). Impact of heat stress on poultry production. Animals, 3(2): 356-369. DOI: https://www.doi.org/10.3390/ani3020356

Liu W, Yuan Y, Sun C, Balasubramanian B, Zhao Z, and An L (2019). Effects of dietary betaine on growth performance, digestive function, carcass traits, and meat quality in indigenous yellow-feathered broilers under long-term heat stress. Animals, 9(8): 506. DOI: https://www.doi.org/10.3390/ani9080506

Lu Q, Wen J, and Zhang H (2007). Effect of chronic heat exposure on fat deposition and meat quality in two genetic types of chicken. Poultry Science, 86(6): 1059-1064. DOI: https://www.doi.org/10.1093/ps/86.6.1059

Marai IFM, Bahgat LB, Shalaby TH, and Abdel-Hafez MA (2000). Response of male lambs to concentrate mixtures given with or without natural clay under Egypt conditions. Annals of Arid Zone, 39: 449-460. Available at: https://epubs.icar.org.in/index.php/AAZ/article/view/65850/28075

Moustafa ES, Alsanie WF, Gaber A, Kamel NN, Alaqil AA, and Abbas AO (2021). Blue-green algae (*Spirulina platensis*) alleviates the negative impact of heat stress on broiler production performance and redox status. Animals, 11(5): 1243. DOI: https://www.doi.org/10.3390/ani11051243

Nawaz AH, Amoah K, Leng QY, Zheng JH, Zhang WL, and Zhang L (2021). Poultry response to heat stress: Its physiological, metabolic, and genetic implications on meat production and quality including strategies to improve broiler production in a warming world. Frontiers in Veterinary Science, 8: 699081. DOI: https://www.doi.org/10.3389/fvets.2021.699081

Ngaira JKW (2007). Impact of climate change on agriculture in Africa by 2030. Scientific Research Essays, 2(7): 238-243. DOI: https://www.doi.org/10.5897/SRE.9000567

Omran OM, Galal A, Mahrous MY, and Badri FB (2020). Impact of heat stress on growth performance and carcass traits in some broiler chickens. Arab Universities Journal of Agricultural Sciences, 28(2): 651-662. Available at:

https://ajs.journals.ekb.eg/article_114159_d1f7c96ed7a83c6122b6750345f8b8d9.pdf

Population reference Bureau (PRB) (2020). World population data sheet. Washington D.C., pp. 1-22. Available at: https://www.prb.org/wp-content/uploads/2020/07/letter-booklet-2020-world-population.pdf

Qu H and Ajuwon KM (2018). Metabolomics of heat stress response in pig adipose tissue reveals alteration of phospholipid and fatty acid composition during heat stress. Journal of Animal Science, 96(8): 3184-3195. DOI: https://www.doi.org/10.1093/jas/sky127

Renaudeau D, Collin A, Yahav S, De Basilio V, Gourdine JL, and Collier RJ (2012). Adaptation to hot climate and strategies to alleviate heat stress in livestock production. Animal, 6(5): 707-728. DOI: https://www.doi.org/10.1017/S1751731111002448

Rostagno MH (2020). Effects of heat stress on the gut health of poultry. Journal of Animal Science, 98: skaa090. DOI: https://www.doi.org/10.3390/poultry3020010

Sapolsky RM, Romero LM, and Munck AU (2000). How do glucocorticoids influence stress responses? Integrating permissive, suppressive, stimulatory, and preparative actions. Endocrine Reviews, 21(1): 55-89. DOI: http://www.doi.org/10.1210/er.21.1.55

Scanes CG (2016). Biology of stress in poultry with emphasis on glucocorticoids and the heterophil to lymphocyte ratio. Poultry Science, 95(9): 2208-2215. DOI: https://www.doi.org/10.3382/ps/pew137

Searchinger T, Waite R, Hanson C, Ranganathan J, Dumas P, and Matthews E (2019). Creating a sustainable food future: A menu of solutions to feed nearly 10 billion people by 2050, Synthesis report. Washington D.C., pp. 1-96. Available at: https://research.wri.org/sites/default/files/2019-07/creating-sustainable-food-future_2_5.pdf

Shao D, Wang Q, Hu Y, Shi S, and Tong H (2019). Effects of cyclic heat stress on the phenotypic response, meat quality and muscle glycolysis of breasts and thighs of yellow feather broilers. Italian Journal of Animal Science, 18(1): 301-308. DOI: https://www.doi.org/10.1080/1828051x.2018.1520051

Song ZH, Cheng K, Zheng XC, Ahmed H, Zhang LL, and Wang T (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. Poultry Science, 97(2): 430-437. DOI: https://www.doi.org/10.3382/ps/pex312

Surai PF and Fisinin VI (2016). Vitagenes in poultry production: Part 3. Vitagene concept development. World's Poultry Science Journal, 72(4): 793-804. DOI: https://www.doi.org/10.1017/S0043933916000751

Tallentire CW, Leinonen I, and Kyriazakis I (2018). Artificial selection for improved energy efficiency is reaching its limits in broiler chickens. Scientific Reports, 8(1): 1168. DOI: https://www.doi.org/10.1038/s41598-018-19231-2

Thornton PK, Van de Steeg J, Notenbaert A, and Herrero M (2009). The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. Agricultural Systems, 101(3): 113-127. DOI: https://www.doi.org/10.1016/j.agsy.2009.05.002

Vasilatos-Younken R (1995). Proposed mechanisms for the regulation of growth hormone action in poultry: Metabolic effects. The Journal of Nutrition, 125(Suppl 6): 1783S-1789S. DOI: https://www.doi.org/10.1093/jn/125.suppl_6.1783S

Wang XJ, Song ZG, Jiao HC, and Lin H (2012a). Skeletal muscle fatty acids shift from oxidation to storage upon dexamethasone treatment in chickens. General and Comparative Endocrinology, 179(3): 319-330. DOI: https://www.doi.org/10.1016/j.ygcen.2012.09.013

Wang XJ, Wei DL, Song ZG, Jiao HC, and Lin H (2012b). Effects of fatty acid treatments on the dexamethasone-induced int ramuscular lipid accumulation in chickens. PLOS One, 7(5): e36663. DOI: https://www.doi.org/10.1371/journal.pone.0036663

Xu Y, Lai X, Li Z, Zhang X, and Luo Q (2018). Effect of chronic heat stress on some physiological and immunological parameters in different breed of broilers. Poultry Science, 97(11): 4073-4082. DOI: https://www.doi.org/10.3382/ps/pey256

Zaboli G, Huang X, Feng X, and Ahn DU (2019). How can heat stress affect chicken meat quality?- A review. Poultry Science, 98(3): 1551-1556. DOI: https://www.doi.org/10.3382/ps/pey399

Zeferino CP, Komiyama CM, Pelicia VC, Fascina VB, Aoyagi MM, Coutinho LL, Sartori JR, and Moura ASAMT (2016). Carcass and meat quality traits of chickens fed diets concurrently supplemented with vitamins C and E under constant heat stress. Animal, 10(1): 163-171. DOI: https://www.doi.org/10.1017/S1751731115001998

Zhang ZY, Jia GQ, Zuo JJ, Zhang Y, Lei J, Ren L, and Feng DY (2012). Effects of constant and cyclic heat stress on muscle metabolism and meat quality of broiler breast fillet and thigh meat. Poultry Science, 91(11): 2931-2937. DOI: https://www.doi.org/10.3382/ps.2012-02255

Zhang M, Dunshea FR, Warner RD, Di Giacomo K, Osei-Amponsah R, and Chauhan SS (2020). Impacts of heat stress on meat quality and strategies for amelioration: A review. International Journal of Biometeorology, 64(9): 1613-1628. DOI: https://www.doi.org/10.1007/s00484-020-01929-6

Zhao JS, Deng W, and Liu HW (2019). Effects of chlorogenic acid-enriched extract from Eucommia Ulmoides leaf on performance, meat quality, oxidative stability, and fatty acid profile of meat in heat-stressed broilers. Poultry Science, 98(7): 3040-3049. DOI: https://www.doi.org/10.3382/ps/pez081

Zuidhof MJ, Schneider BL, Carney VL, Korver DR, and Robinson FE (2014). Growth, efficiency, and yield of commercial broilers from 1957, 1978, and 2005. Poultry Science, 93(12): 2970-2982. DOI: https://www.doi.org/10.3382/ps.2014-04291