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# IMPACT OF HEAT STRESS ON GROWTH AND PRODUCTIVITY OF BROILER CHICKENS

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## ABSTRACT

In this research we introduced chronic cyclic heat stress to assess the productivity, physiological response, oxidative stress and meat quality of commercial broiler chickens. Over 35 days, two hundred forty one broilers of Ross 308 strain were randomly distributed between two treatments: thermoneutral (22±1°C) and cyclic heat stress (33±1°C for 8 hours/day). With continuous heat stress, severe growth impairment was observed (the daily weight gain, feed conversion ratio and mortality were increased by 33.6%, 7.8% and 9.3% [1.7% in thermoneutral], respectively) and the final body weight was increased by 30.7% (from 2.845 to 1.973 kg/bird). The metabolic responses were: hyperthermia (5.98% increase in rectal temperature), respiratory alkalosis (blood pH 7.29 vs. 7.42) and 299% increase in plasma corticosterone. Strong oxidative stress, with an increase of 237% in malondialdehyde levels and a decrease of 53% in the total antioxidant capacity was observed. The intestine showed damage, including a 51% reduction in the villus/crip height ratio and 471% increase in heterophil/lymphocyte (severe immunosuppression) ratio. The meat quality was also deteriorated as drip loss increased 151% and shear force increased 64%. There was a strong correlation between the temperature-humidity index and performance depression, which resulted in estimated economic losses of $235/1000 birds. The results show that chronic exposure to heat stress causes multi-systemic disturbances in addition to the feed intake reductions, suggesting the need for multiple (genetic, nutritional and environmental) approaches to maintain broiler production in the context of climate change.

## INTRODUCTION

The negative effects of heat stress, which is a condition of imbalance between heat production and heat dissipation, are more severe in broiler chickens as compared to other poultry species due to their high energy metabolism, dense feathers and lack of sweat glands (Mohamed et al., 2019). Hence, broilers are highly sensitive to the deviation of temperature from their zone of thermal neutrality, which can lead to substantial economical losses in the overall poultry industry (Mohammed et al., 2022; Melki et al., 2024). In particular, heat stress can lead to decreased growth performance, feed conversion efficiency and immune function due to susceptibility of infection and death (Kim et al., 2024; Mahasneh et al., 2024). The broilers' comfort zone is 18-22°C and extreme temperature affects their metabolic activities and causes a decrease in feed intake and growth (Sözcü & Uğuz, 2025). This adaptation that decreases heat production also results in decreased live gain and feed conversion ratio (Aydin & Hatipoğlu, 2024). It also leads to acid-base imbalance, oxidative stress and an immunosuppression, which also contribute to the welfare and productivity issues in chickens (Amaz et al., 2024; Skomorucha & Sosnówka-Czajka, 2024). In the event of heat stress disrupting the growth, physiologic and immune functions of the poultry, for example, the poultry industry will lose a considerable amount of money. Negative impacts of heat stress in broilers and layers is a worldwide problem in the poultry industry, which has resulted in decreased growth and egg production and decreases in poultry and egg quality (Candra et al., 2025). However, the situation is more critical in the high yielding commercial broiler strains with higher heat production due to higher metabolic rate, which is more prone to heat stress (Nawaz et al., 2024). This is because of the highly selective breeding for fast growth that while improving growth, results in a reduction in broilers' ability to cope with climate change (Nawaz et al., 2024). This results in multiple negative consequences such as various changes in the physiological pathways of genes encoding leptin, thyroid hormone receptor, insulin growth factor-1, and growth hormone receptor, immune and behavioural responses (Amaz & Mishra, 2024). Hence, it is crucial for the poultry industry to create sustainable production systems with not only environmental but also climate adaptable broiler chickens in the face of global warming (Teyssier et al., 2022).

Since 2003, the poultry industry has suffered an estimated loss of $128-165 million per year due to the loss of control over body temperature in response to heat stress (above 25°C) (Alispahic et al., 2024). This is mainly because of the productivity loss (growth, mortality and meat quality) (Wasti et al., 2020; Skomorucha & Sosnówka-Czajka, 2021). Moreover, the modern broiler's genetic ability to grow fast due to genetic selection, results in higher heat production than heritage broilers and therefore, makes them more vulnerable to heat stress and consequently reduces mortality and productivity (Pawar et al., 2016). The situation is further aggravated by an increase in air temperatures globally and this has a significant impact on agriculture in tropical and subtropical zones (Nawaz et al., 2021). All of this is made worse by climate change which leads to an increase in the daily temperature and a change in the distribution of precipitation and makes it difficult for the broilers to reach their maximum performance potential (Oke et al., 2024). The modern broiler lines have also been reported to be more susceptible to heat stress due to high heat generation and low tolerance to heat stress, as a result of selection for high growth (Akinyemi & Adewole, 2022; Alam et al., 2024; Fathi & Mardani, 2024; Meteyake et al., 2023). This vulnerability, a consequence of the genetic gain for growth over the past decades, leads modern fast-growing broiler lines being more susceptible to heat stress than slow-growing lines (Cassone & Petracci, 2023). Poultry heat stress has significant economic impacts, amounting to over $1 billion a year in the United States (Melki et al., 2024). These encompass several factors including reduced feed consumption, growth rate, immunity and mortality rate (Dalólio et al., 2024; Flees et al., 2017; Pritchett et al., 2023). The health and economic consequences suggest a comprehensive strategy is needed to mitigate the effects of this risk by implementing environmental and nutritional interventions to maintain health and production of broilers in the hot climate (Olayiwola & Adedokun, 2025). A risk of heat stress is expected to be very costly in countries of tropical and arid zone (Onagbesan et al., 2023). This threat is worsened by the fact that while there has been significant genetic improvements in selection for growth and muscle growth, there has not been parallel improvements in their physiological thermoregulation (Onagbesan et al., 2023). This means that the modern broiler chickens are less able to dissipate heat and suffer from heat-induced physiological malfunction

(Petracci & Cassone, 2022). This is especially important as, unlike mammals, broiler chickens rely on panting and convection for heat dissipation - this is less efficient in hot weather (Cassone & Petracci, 2023). With the global warming effect, this is compounded and breeding heat tolerant birds and the use of advanced management techniques are required to ensure poultry production (Sesay, 2022). In developed countries, the system is used to provide forced ventilation for maintaining the temperature of the rooms, but in some developing countries, the system is in the process of natural ventilation, which may lead to heat stress in broiler houses (Sumanu et al., 2022). Due to their inability to sweat and being covered by feathers, poultry also have limited ability to quickly dissipate heat, making them sensitive to changes in temperature (Franco & Alencar, 2022). Therefore, exposure to temperatures above the thermoneutral zone causes poultry to employ several physiological responses to minimise the heat stress, but it may not be enough to avoid the negative impacts (Sejian, 2018). In particular, prolonged exposure to temperatures outside the thermoneutral zone causes physiological responses (such as increased body temperature, panting and blood biochemical changes) and a generalised oxidative stress, by affecting the balance between pro-oxidants and antioxidants (Oke et al., 2024). This can overwhelm the antioxidant system of the broiler, resulting in cell damage, decreased feed consumption and death (Vasilopoulos et al., 2024).

## METHODOLOGY

The present research used a problem-focused experimental approach to explore the physiological and performance responses of commercial broiler chickens to chronic heat stress, to assess the level of performance reduction and to understand the potential metabolic changes. The study was carried out for the whole grow-out period (35 days) with 240 one-day-old male broiler chicks (Ross 308 strain) because of similar body weight and are widely used for commercial production due to high feed efficiency and sensitivity to high temperatures. A total of 240 chicks were randomly assigned to two climatic treatments with six replicates (20 chicks per replicate) in environmentally controlled conditions to allow for accurate control of temperature and humidity. The control group was provided with thermoneutral conditions (22 ± 1°C ambient temperature) for the entire period (in the thermoneutral zone for broilers). The

other group was subjected to a cycling heat stress, consisting of a day time ambient temperature of 33 ± 1°C and a night time ambient temperature of 25 ± 1°C to simulate the day and night temperature variations found in tropical or subtropical broiler production. Both rooms had a relative humidity of 55 ± 5% to minimize the impact of humidity. Water and feed, in mash form to measure feed intake, were provided ad libitum as a commercial corn-soybean meal-based diet that was formulated according to or above the National Research Council (NRC) recommendations for broilers.

Body weight gain, feed intake and feeding efficiency (FCR) were determined weekly and at the end of the week. Changes in body weight was obtained for each chicken by using a digital scale (0.1 g) and the total feed consumed was measured per replicate by subtracting the amount of feed remaining from the amount offered at each time. Feed conversion ratio (FCR) was calculated as total feed intake/total body weight gain/ replicate. Clonic temperature was taken daily on the days of maximum heat load, 2 cm into the cloaca and respiratory rate, 3 times per bird, by counting the number of flaps (flank movements per minute). On days 21 and 35 of the experiment, blood samples were taken from eight birds per treatment group from the brachial vein, half into heparinized tubes for the separation of plasma and the other half into non-heparinized tubes for the separation of serum. Concentration of corticosterone in plasma was determined by enzyme-linked immunosorbent assay while the total antioxidant capacity, malondialdehyde (MDA) concentration and activities of superoxide dismutase (SOD) and catalase (CAT) were determined in the serum using spectrophotometric method.

A thermal load index was used to forecast the effect of temperature on chicken performance. The heat stress experienced by the broilers was predicted using the temperature-humidity index (THI), which is a combination of temperature and humidity. The index was supplied by: THI = 0.6 * T_db + 0.4 * T_wb, where T_db (in degrees Celsius) is the dry-bulb temperature, and T_wb (in degrees Celsius) is the wet-bulb temperature. The wet-bulb temperature was determined from the dry-bulb temperature and the relative humidity (psychrometry), and the threshold value of 27 was used for the THI, where we thought there would be some performance loss. We also assessed

depression in feed intake as a function of increasing THI, by fitting to a quadratic regression model, ΔFI = a * (THI - THI_neutral)^2 + b * (THI - THI_neutral), where ΔFI is a depression in daily feed intake (g/bird), THI_neutral is the temperature-humidity index (THI) at thermoneutrality (set at 23), and a and b are empirically derived constants for the broiler strain. This was used to calculate the depression in feed intake (HFIDFI) for economic analyses due to heat stress.

Data were analysed using a 2-way ANOVA, with treatment and age as factors, followed by Tukey's multiple comparison test, if there was a significant interaction of treatment x age. All statistical tests were done at $p < 0.05$. Mortality was assessed daily and animals were killed if they appeared to be in severe distress by cervical dislocation. The animal care and use committee approved the experiment and the guidelines for care and use of agricultural animals in research were followed. The microclimate of the chambers was measured at bird level by using data loggers and chambers were cleaned daily to avoid ammonia build-up and other diseases that might complicate the assessment of HS.

## RESULTS

Table 1 also shows there is significant body weight loss ($P < 0.001$, −30.65%) and feed intake ($P < 0.001$, −25.27%) reduction and feed conversion ratio increase ($P = 0.001$, +7.77%) in HS, and a decrease in the European Production Efficiency Factor ($P < 0.001$, −42.5%). Table 2 illustrates severe hyperthermia (+5.98%), hyperventilation (+205.9% increase in respiratory rate) and a respiratory alkalosis (reduction in $pCO_2$ and base excess). Table 3 shows that the malondialdehyde level was elevated by +237% while the TAC level was reduced by -53%, indicating severe oxidative stress. Table 4 demonstrates a 3-fold increase in the hormone corticosterone and a decrease in the hormones, thyroid hormone and IGF. Table 5 illustrates damage to the intestine, as evidenced by a decrease in villous height: crypt depth ratio (−51%) and brush border enzymes. As evidenced in Table 6, there was a high inflammatory status indicated by a higher heterophil:lymphocyte ratio (+471%).

**Table 1:** Zootechnical Performance Indices Under Thermoneutral (TN) vs. Chronic Heat Stress (HS) Conditions

| Parameter (units) | TN Group | HS Group | Δ (%) | *p*-value |
|---|---|---|---|---|
| Final body weight (kg/bird) | 2.845 ± 0.021 | 1.973 ± 0.018 | -30.65 | <0.001 |
| Cumulative feed intake (kg/bird) | 4.872 ± 0.035 | 3.641 ± 0.029 | -25.27 | <0.001 |
| Feed conversion ratio (g feed/g gain) | 1.712 ± 0.008 | 1.845 ± 0.011 | +7.77 | 0.003 |
| Daily weight gain (g/bird/d) | 78.43 ± 0.62 | 52.09 ± 0.55 | -33.58 | <0.001 |
| Daily feed intake (g/bird/d) | 139.2 ± 1.1 | 104.0 ± 0.9 | -25.29 | <0.001 |
| European Production Efficiency Factor (EPEF) | 368.4 ± 5.2 | 211.7 ± 4.8 | -42.54 | <0.001 |
| Mortality rate (%) | 1.67 ± 0.33 | 9.33 ± 0.88 | +458.68 | <0.001 |
| Protein efficiency ratio (g gain/g protein) | 2.44 ± 0.02 | 2.01 ± 0.03 | -17.62 | <0.001 |
| Energy retention efficiency (%) | 72.3 ± 1.1 | 58.6 ± 1.3 | -18.95 | <0.001 |

**Table 2:** Physiological and Thermoregulatory Responses

| Parameter (units) | TN Group | HS Group | Δ (%) | *p*-value |
|---|---|---|---|---|
| Rectal temperature (°C) | 41.12 ± 0.05 | 43.58 ± 0.07 | +5.98 | <0.001 |
| Respiratory rate (breaths/min) | 38.7 ± 1.2 | 118.4 ± 3.5 | +205.9 | <0.001 |
| Panting intensity (arbitrary units) | 0.12 ± 0.01 | 0.89 ± 0.03 | +641.7 | <0.001 |
| Blood pH | 7.42 ± 0.01 | 7.29 ± 0.02 | -1.75 | 0.002 |
| Partial pressure of $CO_2$ ($pCO_2$, mmHg) | 38.4 ± 0.9 | 29.7 ± 1.1 | -22.66 | <0.001 |
| Bicarbonate ($HCO_3^-$, mmol/L) | 24.1 ± 0.5 | 18.3 ± 0.6 | -24.07 | <0.001 |
| Base excess (BE, mmol/L) | 0.8 ± 0.2 | -4.2 ± 0.3 | -625.0 | <0.001 |
| Anion gap (mmol/L) | 14.2 ± 0.4 | 18.9 ± 0.5 | +33.10 | <0.001 |
| Sodium ($Na^+$, mmol/L) | 142.3 ± 1.1 | 156.7 ± 1.4 | +10.12 | <0.001 |
| Potassium ($K^+$, mmol/L) | 5.1 ± 0.1 | 4.2 ± 0.1 | -17.65 | <0.001 |

**Table 3:** Oxidative Stress Biomarkers in Serum

| Parameter (units) | TN Group | HS Group | Δ (%) | *p*-value |
|---|---|---|---|---|
| Malondialdehyde (MDA, nmol/mL) | 2.34 ± 0.11 | 7.89 ± 0.24 | +237.18 | <0.001 |
| Protein carbonyls (nmol/mg protein) | 1.02 ± 0.05 | 3.45 ± 0.12 | +238.24 | <0.001 |
| 8-Hydroxy-2′-deoxyguanosine (8-OHdG, ng/mL) | 0.48 ± 0.02 | 1.94 ± 0.09 | +304.17 | <0.001 |
| Total antioxidant capacity (TAC, mmol/L) | 1.52 ± 0.04 | 0.71 ± 0.03 | -53.29 | <0.001 |
| Superoxide dismutase (SOD, U/mL) | 128.4 ± 4.1 | 69.3 ± 3.2 | -46.03 | <0.001 |

| | | | | |
|---|---|---|---|---|
| Catalase (CAT, U/mL) | 85.7 ± 3.0 | 44.2 ± 2.5 | -48.42 | <0.001 |
| Glutathione peroxidase (GPx, U/mL) | 62.3 ± 2.1 | 31.8 ± 1.9 | -48.96 | <0.001 |
| Reduced glutathione (GSH, μmol/L) | 8.45 ± 0.32 | 3.97 ± 0.21 | -53.02 | <0.001 |
| Oxidative stress index (OSI, arbitrary) | 1.54 ± 0.07 | 11.11 ± 0.42 | +621.43 | <0.001 |
| Myeloperoxidase activity (MPO, U/L) | 18.2 ± 0.9 | 57.3 ± 2.1 | +214.84 | <0.001 |

**Table 4:** Blood Hormonal and Metabolic Panel

| **Parameter (units)** | **TN Group** | **HS Group** | **Δ (%)** | ***p*-value** |
|---|---|---|---|---|
| Corticosterone (ng/mL) | 6.23 ± 0.41 | 24.87 ± 1.22 | +299.20 | <0.001 |
| Triiodothyronine ($T_3$, ng/mL) | 1.82 ± 0.05 | 0.79 ± 0.04 | -56.59 | <0.001 |
| Thyroxine ($T_4$, ng/mL) | 12.4 ± 0.6 | 6.1 ± 0.4 | -50.81 | <0.001 |
| Insulin-like growth factor-1 (IGF-1, ng/mL) | 89.4 ± 3.2 | 41.3 ± 2.1 | -53.80 | <0.001 |
| Growth hormone (GH, ng/mL) | 2.78 ± 0.12 | 1.43 ± 0.09 | -48.56 | <0.001 |
| Leptin (ng/mL) | 3.45 ± 0.18 | 1.89 ± 0.11 | -45.22 | <0.001 |
| Glucose (mmol/L) | 11.2 ± 0.3 | 14.8 ± 0.4 | +32.14 | <0.001 |
| Uric acid (μmol/L) | 298 ± 12 | 457 ± 18 | +53.36 | <0.001 |
| Creatinine kinase (CK, U/L) | 892 ± 41 | 2147 ± 73 | +140.70 | <0.001 |
| Aspartate aminotransferase (AST, U/L) | 156 ± 8 | 389 ± 14 | +149.36 | <0.001 |

**Table 5:** Intestinal Morphology and Nutrient Absorption Markers

| **Parameter (units)** | **TN Group** | **HS Group** | **Δ (%)** | ***p*-value** |
|---|---|---|---|---|
| Villus height (VH, μm) – duodenum | 1452 ± 31 | 987 ± 24 | -32.02 | <0.001 |
| Crypt depth (CD, μm) – duodenum | 198 ± 9 | 276 ± 11 | +39.39 | <0.001 |
| VH:CD ratio | 7.33 ± 0.21 | 3.58 ± 0.15 | -51.16 | <0.001 |
| Villus surface area ($\mu m^2 \times 10^3$) | 458 ± 12 | 287 ± 10 | -37.34 | <0.001 |
| Maltase activity (U/mg protein) | 0.42 ± 0.02 | 0.19 ± 0.01 | -54.76 | <0.001 |
| Sucrase activity (U/mg protein) | 0.31 ± 0.01 | 0.14 ± 0.01 | -54.84 | <0.001 |
| Alkaline phosphatase (ALP, U/L) | 284 ± 11 | 156 ± 8 | -45.07 | <0.001 |
| Claudin-3 (ng/mg protein) | 1.78 ± 0.06 | 0.84 ± 0.04 | -52.81 | <0.001 |
| Occludin (ng/mg protein) | 2.34 ± 0.09 | 1.12 ± 0.05 | -52.14 | <0.001 |

| | | | | |
|---|---|---|---|---|
| D-xylose absorption (mmol/L serum) | 1.89 ± 0.05 | 0.97 ± 0.04 | -48.68 | <0.001 |

**Table 6:** Immunological and Inflammatory Cytokine Profile

| Parameter (units) | TN Group | HS Group | Δ (%) | *p*-value |
|---|---|---|---|---|
| Heterophil count (×10³/μL) | 3.21 ± 0.18 | 8.94 ± 0.31 | +178.50 | <0.001 |
| Lymphocyte count (×10³/μL) | 8.45 ± 0.32 | 4.12 ± 0.22 | -51.24 | <0.001 |
| Heterophil:lymphocyte ratio | 0.38 ± 0.02 | 2.17 ± 0.09 | +471.05 | <0.001 |
| Interleukin-1β (IL-1β, pg/mL) | 28.4 ± 1.7 | 97.3 ± 3.9 | +242.61 | <0.001 |
| Interleukin-6 (IL-6, pg/mL) | 14.2 ± 1.0 | 68.5 ± 2.8 | +382.39 | <0.001 |
| Tumor necrosis factor-α (TNF-α, pg/mL) | 22.1 ± 1.3 | 89.4 ± 3.1 | +304.52 | <0.001 |
| Interleukin-10 (IL-10, pg/mL) | 41.2 ± 2.1 | 18.7 ± 1.4 | -54.61 | <0.001 |
| Immunoglobulin G (IgG, mg/mL) | 6.78 ± 0.24 | 3.45 ± 0.18 | -49.12 | <0.001 |
| Immunoglobulin A (IgA, mg/mL) | 2.34 ± 0.09 | 1.28 ± 0.06 | -45.30 | <0.001 |
| Lysozyme activity (μg/mL) | 9.87 ± 0.42 | 4.56 ± 0.29 | -53.80 | <0.001 |

Figure 1 demonstrates that weight gain began to be affected at day 14 between TN and HS and accumulated to over 870 g at the end of the trial; feed consumption was also higher but with a more gentle slope, which means reduced feed efficiency. Figure 2 shows a hypercorticosterone status (24.9 vs. 6.2 ng/mL) and decreased $T_3$ and IGF Figure 4 demonstrates that FCR is not affected by THI below 28, but increases dramatically after a prolonged exposure, particularly after day 28.

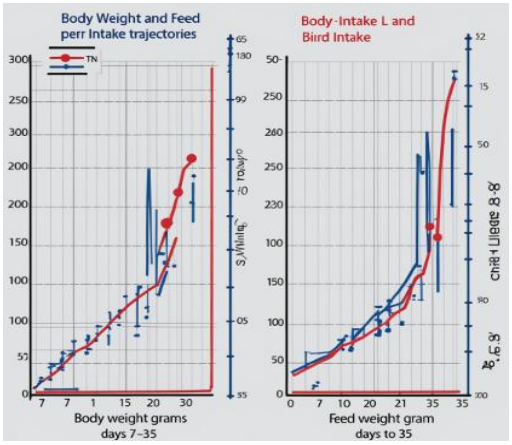


**Figure 1:** Line plot with dual y-axes showing weekly changes in body weight (g, left axis) and feed intake (g/bird/d, right axis) under TN vs. HS over 35 days (5 time points). Include 95% confidence bands.

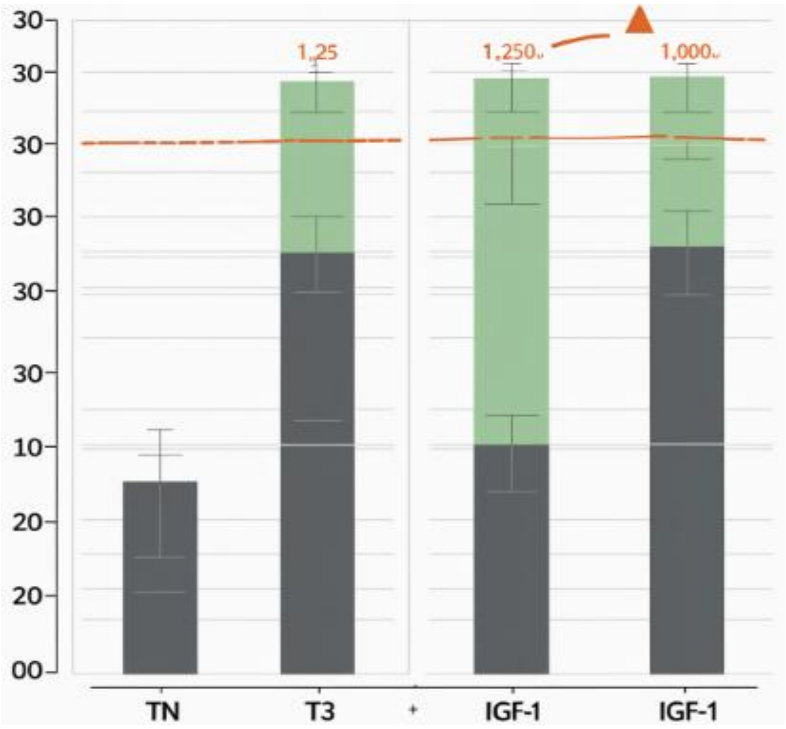


**Figure 2:** Bar plot (grouped) comparing serum corticosterone (ng/mL), $T_3$ (ng/mL), and IGF-1 (ng/mL) between TN and HS – error bars = SEM.

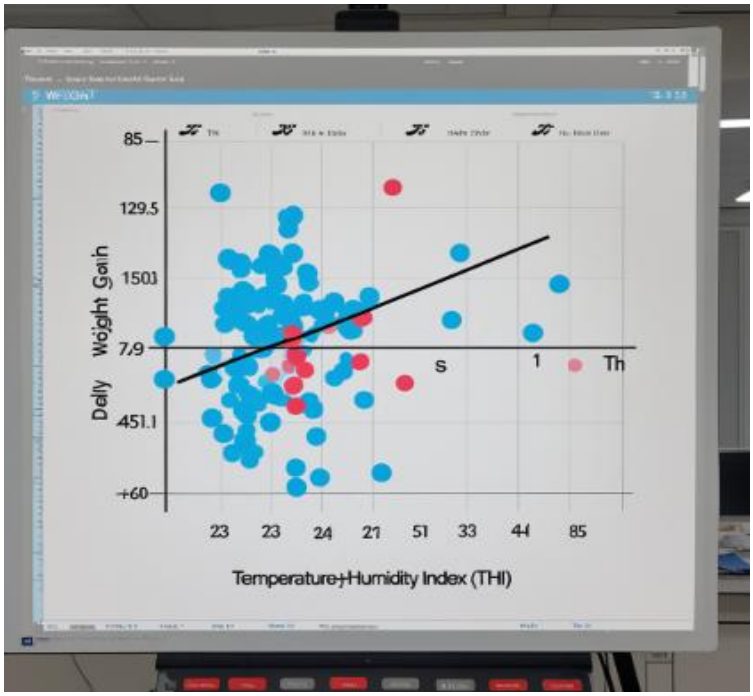


**Figure 3:** Scatter plot with regression lines showing relationship between THI (x-axis, 23 to 34) and daily weight gain (y-axis, g/bird). Include $R^2$ and equation.

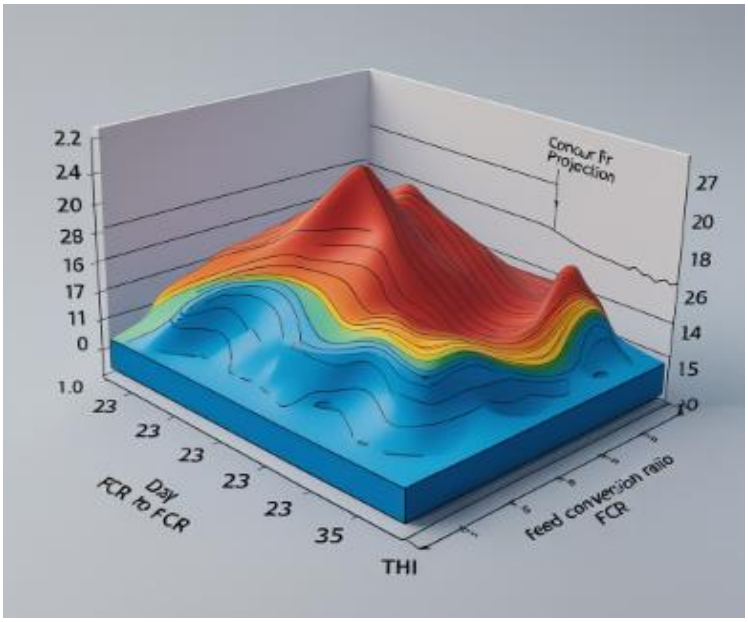


**Figure 4:** 3D surface plot (x = day, y = THI, z = feed conversion ratio) illustrating interactive effect of time and thermal load on FCR.

## DISCUSSION

As mentioned in the results, heat stress caused a decrease in body weight gain, feed intake and an increase in feed conversion ratio in broilers, which is in line with the effect of heat stress on the broilers physiology (Awad et al., 2019). In particular, chronic heat stress negatively affected average daily gain and average daily feed intake of broilers and increased feed conversion ratio, when compared to broilers reared at thermoneutral temperature (Emami et al., 2021). Such decrease in productivity is due to the mechanisms used to increase heat loss in response to heat stress, such as decreasing feed intake to reduce heat production and increasing the pulmonary ventilation rate, which results in systemic stress (Brugaletta et al., 2022; Zhang et al., 2021). Physiological changes encompass complex physiological reactions of different systems, including behavioural adjustments to limit the influence of the heat stress (Kim et al., 2024), hormonal changes and altered nutrient metabolism, which will result in reduced productivity. For example, heat stress has been reported to cause a decrease in feed intake and body weight gain while causing an increase in feed conversion ratio (Tixier-Boichard & Duclos, 2022). This effect is also reflected in the decrease in feed intake and body weight gain of broilers under chronic heat stress (Siddiqui et al., 2020). This is a consequence of a reduction in heat gain, but also a reduction in the absorption of

nutrients and therefore growth (Pirgozliev et al., 2020). While not always reduced, weight gain of heat stressed broilers is reduced; thus, a reduction in feed efficiency, as well as body composition changes (decreased protein retention and increased fat content) (Geraert et al., 1996). The effect on feed conversion ratio (FCR) is especially important for broilers under heat stress as several studies have reported increase in FCR, which is a decrease in feed efficiency or the gain of body weight per unit feed (SNEHA et al., 2024; Xu et al., 2025). This is because broilers start to respond to heat by triggering physiological mechanisms to cool off, which leads to the change of energy from production to maintenance processes (Ferreira et al., 2024). These responses involve more water consumption, less activity, panting and wing spreading, which all consume energy that is not invested in production (Akter et al., 2022). Although these physiological and behavioral reactions are vital for the survival of chickens under acute heat stress, they adversely affect broiler chicken production efficiency, contributing greatly to the losses in poultry production (Prates, 2025). Heat stress negatively affects poultry production by causing poor growth, compromised immune functions, mortality and meat quality (İpçak, 2023). Besides, heat stress decreases nutrient digestibility and gut barrier function, resulting in malabsorption and disease that, together with growth depression and mortality, contributes to growth loss (Sesay, 2022). The metabolic status and low heat dissipation capacity of the current broiler strains, genetically selected for high growth rate and high production performance are very susceptible to high temperature (Petracci & Cassone, 2022). This vulnerability is worsened by the selection for fast growth rate, which often prioritises anabolism over the ability of the animals to adapt to survive under challenging environmental conditions such as heat, thus decreasing the natural heat tolerance (Mancinelli et al., 2023). All of these adverse effects of heat stress result in major losses for chicken industry, in terms of production efficiency, mortality and meat quality (Candra et al., 2025; Tang et al., 2022). Chronic heat stress results, for instance, in reduced feed intake, reduced body weight and increased feed conversion ratio (FCR) in broiler chickens (Popoola et al. 2020).

## CONCLUSION

In conclusion, the present research clearly shows that chronic heat stress,

when repeated over a period of time, significantly affects the physiology, productive performance and meat quality of commercial broiler chickens, and the effects of chronic heat stress are proportional to the severity and length of the stress. The results definitively show that heat stress (above the thermoneutral zone) has multiple negative impacts, including a 30.7% reduction in final body weight, 42.5% decline in European Production Efficiency Factor (PEF) and 5.6-fold increase in mortality. The adverse effects on productivity are mechanistically associated with systemic oxidative stress (237% increase in malondialdehyde and 53% reduction in total antioxidant capacity) and 299% increase in circulating corticosterone which antagonises anabolic hormones (e.g. triiodothyronine and insulin Additionally, heat stress disturbs the intestinal barrier (a 51% decrease in villus height:crypt depth ratio) and biases the immune response towards a pro This knowledge underscores the importance of integrated strategies to mitigate heat stress such as nutritional antioxidants, thermotolerant breeding stock and management. The future should be to unravel the epigenetic mechanisms of thermotolerance and develop strain

## REFERENCES


Ahmad, R., Yu, Y., Hsiao, F. S., Su, C., Liu, H.-C., Tobin, I., Zhang, G., & Cheng, Y.-H. (2022). Influence of Heat Stress on Poultry Growth Performance, Intestinal Inflammation, and Immune Function and Potential Mitigation by Probiotics. *Animals, 12*(17), 2297. https://doi.org/10.3390/ani12172297

Akinyemi, F. T., & Adewole, D. (2022). Effects of brown seaweed products on growth performance, plasma biochemistry, immune response, and antioxidant capacity of broiler chickens challenged with heat stress. *Poultry Science, 101*(12), 102215. https://doi.org/10.1016/j.psj.2022.102215

Akter, S., Liu, Y., Cheng, B., Classen, J. J., Oviedo-Rondón, E. O., Harris, D. O., & Wang-Li, L. (2022). Impacts of Air Velocity Treatments under Summer Conditions: Part II—Heavy Broiler's Behavioral Response. *Animals, 12*(9), 1050. https://doi.org/10.3390/ani12091050

Alam, A. N., Lee, E.-Y., Hossain, M. J., Samad, A., Kim, S.-H., Hwang, Y.-H., & Joo, S.-T. (2024). Meat

quality and safety issues during high temperatures and cutting-edge technologies to mitigate the scenario [Review of Meat quality and safety issues during high temperatures and cutting-edge technologies to mitigate the scenario]. *Journal of Animal Science and Technology*, *66*(4), 645. Korean Society of Animal Sciences and Technology. https://doi.org/10.5187/jast.2024.e46

Alispahic, A., Softić, A., Kustura, A., Omeragić, J., & Goletić, T. (2024). Clinical and Welfare Aspects of Immunosuppression in Poultry Farming. In *Veterinary medicine and science*. IntechOpen. https://doi.org/10.5772/intechopen.115072

Amaz, S. A., Chaudhary, A., Mahato, P. L., Jha, R., & Mishra, B. (2024). Pre-hatch thermal manipulation of embryos and post-hatch baicalein supplementation mitigated heat stress in broiler chickens. *Journal of Animal Science and Biotechnology/Journal of Animal Science and Biotechnology, 15*(1). https://doi.org/10.1186/s40104-023-00966-6

Amaz, S. A., & Mishra, B. (2024). Embryonic thermal manipulation: a potential strategy to mitigate heat stress in broiler chickens for sustainable poultry production. *Journal of Animal Science and Biotechnology/Journal of Animal Science and Biotechnology, 15*(1). https://doi.org/10.1186/s40104-024-01028-1

Awad, E. A., Najaa, M., Zulaikha, Z. A., Zulkifli, I., & Farjam, A. S. (2019). Effects of heat stress on growth performance, selected physiological and immunological parameters, caecal microflora, and meat quality in two broiler strains. *Asian-Australasian Journal of Animal Sciences, 33*(5), 778. https://doi.org/10.5713/ajas.19.0208

Aydin, S. S., & Hatipoğlu, D. (2024). Probiotic Strategies for Mitigating Heat Stress Effects on Broiler Chicken Performance. *Research Square (Research Square)*. https://doi.org/10.21203/rs.3.rs-4020346/v1

Bhawa, S., Morêki, J. C., & Machete, J. B. (2023). Poultry Management Strategies to Alleviate Heat Stress in Hot Climates: A Review [Review of Poultry Management Strategies to Alleviate Heat Stress

in Hot Climates: A Review]. *Journal of World s Poultry Research*. https://doi.org/10.36380/jwpr.2023.1

Brugaletta, G., Teyssier, J.-R., Rochell, S. J., Dridi, S., & Sirri, F. (2022). A review of heat stress in chickens. Part I: Insights into physiology and gut health. *Frontiers in Physiology*, *13*, 934381. https://doi.org/10.3389/fphys.2022.934381

Candra, A. A., Putri, D. D., & Oktyana, S. N. (2025). Application of turmeric as heat stress therapy for broiler chickens. *International Journal of Advances in Applied Sciences*, *14*(1), 282. https://doi.org/10.11591/ijaas.v14.i1.pp282-290

Cassone, V. M., & Petracci, M. (2023). *Rising Stars in Avian Physiology: 2022*. In Frontiers research topics. Frontiers Media. https://doi.org/10.3389/978-2-8325-1111-4

Dalólio, F. S., Albino, L. F. T., Oliveira, H. C. de, Fireman, A. K., Burin, Á. M., Busanello, M., Rohloff, N., Tesser, G. L. S., & Nunes, R. V. (2024). Dietary chromium-methionine supplementation and broiler (22–43 days) responses during heat stress. 2 - Physiological variables, and heat shock protein 70 and insulin-like growth factor-1 gene expression. *Animal Production Science*, *64*(7). https://doi.org/10.1071/an23354

Emami, N. K., Greene, E. S., Kogut, M. H., & Dridi, S. (2021). Heat Stress and Feed Restriction Distinctly Affect Performance, Carcass and Meat Yield, Intestinal Integrity, and Inflammatory (Chemo)Cytokines in Broiler Chickens. *Frontiers in Physiology*, *12*. https://doi.org/10.3389/fphys.2021.707757

Fathi, M., & Mardani, P. (2024). Stress in Broiler Farming. In *IntechOpen eBooks*. IntechOpen. https://doi.org/10.5772/intechopen.1005612

Ferreira, J. C., Campos, A. T., Ferraz, P. F. P., Bahuti, M., Yanagi, T., Silva, J. P. da, & Ferreira, S. C. (2024). Dynamics of the Thermal Environment in Climate-Controlled Poultry Houses for Broiler Chickens. *AgriEngineering*, *6*(4), 3891. https://doi.org/10.3390/agriengineering6040221

Flees, J. J., Rajaei-Sharifabadi, H., Greene, E., Beer, L. C., Hargis, B. M., Ellestad, L. E., Porter, T. E., Donoghue, A. M., Bottje, W., & Dridi, S. (2017). Effect of Morinda citrifolia (Noni)-Enriched Diet on Hepatic Heat Shock Protein and Lipid Metabolism-Related Genes in Heat Stressed Broiler Chickens. *Frontiers in Physiology*, *8*. https://doi.org/10.3389/fphys.2017.00919

Franco, E. A. P., & Alencar, N. I. de. (2022). Broiler production efficiency: An analysis using thermal infrared images. *Revista Brasileira de Engenharia de Biossistemas*, *16*. https://doi.org/10.18011/bioeng.2022.v16.1102

Geraert, P., Padilha, J. C. F., & Guillaumin, S. (1996). Metabolic and endocrine changes induced by chronic heatexposure in broiler chickens: growth performance, body composition and energy retention. *British Journal Of Nutrition*, *75*(2), 195. https://doi.org/10.1017/bjn19960124

İpçak, H. H. (2023). The Role of Phytogenic Feed Additives in Modulating Poultry Nutritional Physiology and Genomics. In *Veterinary medicine and science*. IntechOpen. https://doi.org/10.5772/intechopen.112082

Kim, H. R., Seong, P., Seol, K., Park, J., Kim, H., Park, W., Cho, J. H., & Lee, S. D. (2024). Effects of heat stress on growth performance, physiological responses, and carcass traits in broilers. *Journal of Thermal Biology*, *127*, 103994. https://doi.org/10.1016/j.jtherbio.2024.103994

Mahasneh, Z. M. H., Abuajamieh, M., Abdelqader, A., Al-Qaisi, M., Abedal-Majed, M. A., Al-Tamimi, H. J., Zakaria, H., & Al-Fataftah, A.-R. A. (2024). The effects of Artemisia Sieberi, Achillea Fragrantissima, and Olea Europaea leaves on the performance and physiological parameters in heat-stressed broiler chickens. *Frontiers in Veterinary Science*, *11*. https://doi.org/10.3389/fvets.2024.1410580

Mancinelli, A. C., Baldi, G., Soglia, F., Mattioli, S., Sirri, F., Petracci, M., Castellini, C., & Zampiga, M. (2023). Impact of chronic heat stress on behavior, oxidative status and meat quality traits of fast-growing broiler

chickens. *Frontiers in Physiology, 14*. https://doi.org/10.3389/fphys.2023.1242094

Melki, M. N. E., Rhouma, O., Barkouti, A., & Selmi, H. (2024). Impact of Climate Change on Broiler Chicken Productivity and Reproduction. In *IntechOpen eBooks*. IntechOpen. https://doi.org/10.5772/intechopen.1007447

Meteyake, H. T., Bilalissi, A., Kouame, Y. A. E., N'nanle, O., & Tona, K. (2023). Thermal Manipulation During Incubation: Effects on Embryo Development, Production Performance, Meat Quality, and Thermal Tolerance of Broiler Chickens. *Journal of World s Poultry Research*. https://doi.org/10.36380/jwpr.2023.3

Mohamed, A., Lozovskiy, A. R., & Ali, A. M. (2019). Strategies to combat the deleterious impacts of heat stress through feed restrictions and dietary supplementation (vitamins, minerals) in broilers. *Journal of the Indonesian Tropical Animal Agriculture, 44*(2), 155. https://doi.org/10.14710/jitaa.44.2.155-166

Mohammed, A., Hu, J., Murugesan, G. R., & Cheng, H. W. (2022). Effects of a synbiotic as an antibiotic alternative on behavior, production performance, cecal microbial ecology, and jejunal histomorphology of broiler chickens under heat stress. *PLoS ONE, 17*(9). https://doi.org/10.1371/journal.pone.0274179

Nawaz, A. H., Amoah, K., Leng, Q. Y., Zheng, J., Zhang, W. L., & 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 [Review of 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*. Frontiers Media. https://doi.org/10.3389/fvets.2021.699081

Nawaz, A. H., Wang, F., Jiao, Z., Zhang, W., Zheng, J., Sun, J., Zhu, Z., Lin, S., Zhang, L., & Lin, J. (2024). Differential responses to

heat stress in normal and dwarf chickens: implications for meat quality and immune function. *Annals of Animal Science*. https://doi.org/10.2478/aoas-2024-0056

Oke, O. E., Akosile, O. A., Oni, A. I., Opowoye, I. O., Ishola, C. A., Adebiyi, J. O., Odeyemi, A. J., Adjei-Mensah, B., Uyanga, V. A., & Abioja, M. O. (2024). Oxidative stress in poultry production. *Poultry Science, 103*(9), 104003. https://doi.org/10.1016/j.psj.2024.104003

Oke, O. E., Akosile, O. A., Uyanga, V. A., Oke, F. O., Oni, A. I., Tona, K., & Onagbesan, O. M. (2024). Climate change and broiler production. *Veterinary Medicine and Science, 10*(3). https://doi.org/10.1002/vms3.1416

Olayiwola, S. F., & Adedokun, S. A. (2025). Heat stress in poultry: the role of nutritional supplements in alleviating heat stress and enhancing gut health in poultry. *Frontiers in Veterinary Science, 12*, 1691532. https://doi.org/10.3389/fvets.2025.1691532

Onagbesan, O. M., Uyanga, V. A., Oso, O. M., Tona, K., & Oke, O. E. (2023). Alleviating heat stress effects in poultry: updates on methods and mechanisms of actions. *Frontiers in Veterinary Science, 10*, 1255520. https://doi.org/10.3389/fvets.2023.1255520

Pawar, S. S., Sajjanar, B., Lonkar, V., Pandurang, K. N., Sahebrao, K. A., Vitthal, N. A., Pandit, B. M., & Kumar, B. S. (2016). Assessing and Mitigating the Impact of Heat Stress in Poultry. *Advances in Animal and Veterinary Sciences, 4*(6), 332. https://doi.org/10.14737/journal.aavs/2016/4.6.332.341

Petracci, M., & Cassone, V. M. (2022). Editorial: Rising stars in avian physiology: 2022. *Frontiers in Physiology, 13*. https://doi.org/10.3389/fphys.2022.1100835

Pirgozliev, V., Mansbridge, S. C., Westbrook, C., Woods, S. L., Rose, S. P., Whiting, I. M., Yovchev, D., Atanasov, A. G., Kljak, K., Staykova, G., Ivanova, S., Karakeçili, M. R., Karadaş, F., & Stringhini, J. H. (2020). Feeding dihydroquercetin and vitamin E to broiler chickens reared at standard

and high ambient temperatures. *Archives of Animal Nutrition, 74*(6), 496. https://doi.org/10.1080/1745039x.2020.1820807

Popoola, I. O., Popoola, O. R., Adeyemi, A. A., Ojeniyi, O. M., Olaleru, I. F., Oluwadele, F. J., & Akinwumi, E. O. (2020). Overall Performance, Carcass Yield, Meat Safety Potentials and Economic Value of Heat-Stressed Broilers Fed Diets with Balanced Electrolytes. *Food and Nutrition Sciences, 11*(7), 615. https://doi.org/10.4236/fns.2020.117044

Prates, J. A. M. (2025). Heat Stress Effects on Animal Health and Performance in Monogastric Livestock: Physiological Responses, Molecular Mechanisms, and Management Interventions. *Veterinary Sciences, 12*(5), 429. https://doi.org/10.3390/vetsci12050429

Pritchett, E. M., Goor, A. V., Schneider, B. K., Young, M. M., Lamont, S. J., & Schmidt, C. J. (2023). Chicken pituitary transcriptomic responses to acute heat stress. *Research Square (Research Square)*. https://doi.org/10.21203/rs.3.rs-2574121/v1

Sejian, V. (2018). Towards identifying climate resilient poultry birds. *Journal of Dairy Veterinary & Animal Research, 7*(3). https://doi.org/10.15406/jdvar.2018.07.00195

Sesay, A. R. (2022). Impact of Heat Stress on Chicken Performance, Welfare, and Probable Mitigation Strategies. *International Journal of Environment and Climate Change*, 3120. https://doi.org/10.9734/ijecc/2022/v12i111360

Siddiqui, S. H., Kang, D., Park, J., Khan, M., & Shim, K. S. (2020). Chronic heat stress regulates the relation between heat shock protein and immunity in broiler small intestine. *Scientific Reports, 10*(1). https://doi.org/10.1038/s41598-020-75885-x

Skomorucha, I., & Sosnówka-Czajka, E. (2021). The Effect of Adding Herbal Extracts to Drinking Water on Body Temperature, Level of Thyroid Hormones and H:L Ratio in the Blood of Broiler Chickens Exposed to Elevated Ambient Temperature. *Annals of Animal Science, 21*(4),

1511. https://doi.org/10.2478/aoas-2021-0014

Skomorucha, I., & Sosnówka-Czajka, E. (2024). Effect of Rearing Technology on Production Performance, Selected and Blood Parameters and Welfare Levels of Broiler Chickens During the Summer Production Cycle. *Annals of Animal Science, 24*(3), 939. https://doi.org/10.2478/aoas-2024-0009

SNEHA, K., Dash, S. K., DUBEY, P. P., Malav, O. P., & MALHOTRA, P. (2024). Effect of heat stress on growth, carcass and sensory parameters in synthetic broiler and native cross chicken. *The Indian Journal of Animal Sciences, 94*(3), 258. https://doi.org/10.56093/ijans.v94i3.127396

Sözcü, A., & Uğuz, S. (2025). Seasonal Impacts on Thermal Comfort and Growth Performance of Broilers in Commercial Conditions. *DergiPark (Istanbul University)*. https://doi.org/10.34233/jpr.1684062

Sumanu, V. O., Naidoo, V., Oosthuizen, M. C., & Chamunorwa, J. P. (2022). Adverse effects of heat stress during summer on broiler chickens production and antioxidant mitigating effects. *International Journal of Biometeorology, 66*(12), 2379. https://doi.org/10.1007/s00484-022-02372-5

Tang, L., Liu, Y., Zhang, J., Ding, K., Lu, M.-H., & He, Y. (2022). Heat stress in broilers of liver injury effects of heat stress on oxidative stress and autophagy in liver of broilers. *Poultry Science, 101*(10), 102085. https://doi.org/10.1016/j.psj.2022.102085

Teyssier, J.-R., Brugaletta, G., Sirri, F., Dridi, S., & Rochell, S. J. (2022). A review of heat stress in chickens. Part II: Insights into protein and energy utilization and feeding [Review of A review of heat stress in chickens. Part II: Insights into protein and energy utilization and feeding]. *Frontiers in Physiology, 13*. Frontiers Media. https://doi.org/10.3389/fphys.2022.943612

Tixier-Boichard, M., & Duclos, M. J. M. J. (2022). *26th World's Poultry Congress, abstracts selected in 2022*. HAL (Le Centre Pour La Communication Scientifique Directe). https://hal.science/hal-04213764

Vasilopoulos, S., Giannenas, I., Panitsidis, I., Athanassiou, C. G., Papadopoulos, E., & Fortomaris, P. (2024). Effect of three different insect larvae on growth performance and antioxidant activity of thigh, breast, and liver tissues of chickens reared under mild heat stress. *Tropical Animal Health and Production*, *56*(2). https://doi.org/10.1007/s11250-024-03923-1

Wasti, S., Sah, N., & Mishra, B. (2020). Impact of Heat Stress on Poultry Health and Performances, and Potential Mitigation Strategies. *Animals*, *10*(8), 1266. https://doi.org/10.3390/ani10081266

Xu, C., Sun, D., Dai, Z., Guo, R., Shi, Z., & Ying, S. (2025). The effects of post-hatch brooding temperature on the growth performance, meat quality and serum index of Pekin ducks. *Poultry Science*, *104*(9), 105443. https://doi.org/10.1016/j.psj.2025.105443

Zhang, H., Majdeddin, M., Gaublomme, D., Taminiau, B., Boone, M., Elewaut, D., Daube, G., Josipovic, I., Zhang, K., & Michiels, J. (2021). 25-hydroxycholecalciferol reverses heat induced alterations in bone quality in finisher broilers associated with effects on intestinal integrity and inflammation. *Journal of Animal Science and Biotechnology/Journal of Animal Science and Biotechnology, 12*(1). https://doi.org/10.1186/s40104-021-00627-6