The effects of intermittent feeding and cold water on welfare status and meat quality in broiler chickens reared under daily heat stress

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Abstract

This study was aimed to determine the effects of feeding type (ad libitum: AF and intermittent: IF) and water temperature (normal: NW and cold: CW) treatments on welfare status and meat quality in fast-growing broiler chickens reared under daily heat stress between 22 and 42 days of age. The chickens’ panting rate and rectal temperature were determined at 4, 5, and 6 weeks of age and twice a week in 3 female and 3 male chickens in each pen. Welfare traits such as foot pad dermatitis (FPD), hock burn (HB), breast burn (BB), and leg problems (LP) were examined individually at 42 days of age. At day 43, 3 male and 3 female chickens per pen were randomly selected and slaughtered after an 8-h fasting period; pH and color (lightness (L*), redness (a*), and yellowness (b*)) of breast and thigh meat were determined. AF × CW chickens had significantly higher panting rates at all ages than the other groups (P < 0.05). While FPD and LP were not affected by feeding type and water temperature treatments, interaction effects on HB and BB were found significant (P < 0.05). The HB and BB levels were the lowest in AF × NW chickens (P < 0.05). While treatments did not change to any color traits in breast meat (P > 0.05), interactions significantly affected the yellowness (b*) value in the thigh (P < 0.05). In conclusion, management practices such as IF and CW in fast-growing broilers could not completely reduce the undesirable effects of heat stress on some welfare and meat quality traits, and in some cases, even caused more negativity.

Keywords Broiler · Heat stress · Intermittent feeding · Cold water · Foot pad dermatitis · pH

Introduction

Birds are under great challenge at high environmental temperatures due to the absence of sweat glands and the well-insulated feather coverage (Lara and Rostagno 2013; Noubandiguim et al. 2021). High ambient temperatures in broiler production can cause detrimental effects on physiological, immunity, welfare, health, performance, meat quality, and serious economic losses (Hristov et al. 2018; Erensoy et al. 2020a). Numerous studies have been conducted on the sustainability of better growth and feed efficiency traits by reducing body heat production and providing better heat dissipation in hot environmental conditions (Cahaner et al. 1993; Sahraei 2012; Park et al. 2013; Erensoy et al. 2020a). Due to selection for fast growth, modern broilers have become more sensitive to heat stress (Erensoy et al. 2020a,b). Increased body weight has contributed to the development of some welfare problems such as foot pad dermatitis (FPD), hock burn (HB), breast burn (BB), and leg problems (LP) (Dawkins et al. 2004; Haslam et al. 2007). In addition, heat stress can increase the incidence and severity of these problems (Mello et al. 2015). There were also many studies reporting that acute or chronic heat stress negatively affects the meat quality of broilers (Sandercock et al. 2001; Zaboli et al. 2019) and accelerates the development of PSE syndrome (pale, soft, and exudative) in breast meat (Zhang et al. 2012; Shakeri et al. 2020). Among the various factors affecting meat quality, pH and color are the most widely accepted chemical indicators (El Rammouz et al. 2004; Le Bihan-Duval et al. 1999, 2008; Berri et al. 2001). Petracci et al. (2004), Akşit et al. (2006), and Zaboli et al. (2019) reported that acute heat stress could decrease pH, redness, and yellowness and increase breast meat lightness in broilers.
The accompanying heat stress to excessive live weight makes it challenging to manage in modern broilers, which are already vulnerable in many aspects such as physiological, welfare, and health. Our previous study (Erensoy et al. 2020a) had already demonstrated the effects of feeding type and water temperature on performance and carcass traits. In this study, we hypothesized that these management tools (intermittent feeding and cold water) could also improve some welfare and meat quality traits under heat stress conditions. This study was aimed to determine the effects of feeding type (AF and IF) and water temperature (NM and CW) treatments on welfare status and meat quality in broiler chickens reared under daily heat stress during 22–42 days of age.

Materials and methods

Chicken and housing material

This study was carried out in the experimental farm of Ondokuz Mayıs University, Faculty of Agriculture, between June and August 2019. The chicken and feed material in this study were the same as in Erensoy et al. (2020a).

This study was started with a total of 320 Anadolu-T broiler chickens at 21 days of age. In the study, heat stress treatment and data collection procedures were carried out between 22 and 42 days of age. The experiment was carried out in a fully environmentally controlled house with automatic heating, ventilation, and lighting equipment. In order to eliminate the effects that may arise from the lighting on the treatments, 24-h continuous lighting was applied. All chickens were fed ad libitum until 21 days of age. They were fed with standard broiler starter ration (3000 kcal/kg ME, 23% CP) during the first week, followed by chick feed (3100 kcal/kg ME, 22% CP) until 28 days of age, chicken feed (3100 kcal/kg ME, 21% CP) between 29 and 35 days, and finisher feed (3100 kcal/kg ME, 18% CP) until 42 days of age. Water was also given ad libitum throughout the entire experimental period. The pen dimensions were 1.0 × 1.5 m and each with a 15-kg-capacity round feeder and two nipple drinkers.

Experimental design

The experimental design of this study was in the same procedure as in Erensoy et al. (2020a) and designed as a 2 × 2 factorial design including two feeding systems (AL, ad libitum feeding; IF, intermittent feeding) and two water temperature (NW, normal water; CW, cold water) treatments. A total of 320 broiler chickens were randomly distributed in each group (AF × NW, AF × CW, IF × NW, and IF × CW) at 21 days of age, with four replicates and 20 chickens. Stocking density was 13.3 chickens/m². Broilers in the AL group were fed ad libitum for 24 h and IF chickens were daily fasted for 6 h between 11 and 17 h during the experiment (between 22 and 42 days). NW chickens consumed tap water (avg. 24.9 °C), and CW chickens more chilled water (avg. 16.4 °C) freely for 24 h. The light intensity in all pens was approximately 20 and 25 lux. Heat stress was applied between 11 and 17 h every day between 22 and 42 days of age. Temperature and relative humidity values were 30 °C and 61.4%, and 25.3 °C and 70.2%, respectively, during the hours with (11–17 h) and without (18–10 h) heat treatment.

Data collection

Heat stress indicators

At the end of the 3 weeks of age, all chickens were tagged with wing band, individual live weights were taken, and ten males and ten females were randomly distributed to each pen. The birds’ panting rate and rectal temperature were determined at 4, 5, and 6 weeks of age and twice a week in three female and three male broilers in each pen in the middle of the heat stress duration (at 14h). In order not to affect body temperature, firstly, the panting rate was determined in each observation. While the chicken was in the lying position, the number of panting movements for 1 min was counted by the same person and it was recorded as panting rate (panting count/1 min). Rectal temperature was measured in the same animals with a rectal thermometer with a sensitivity of 0.1 °C for 2 min and 2 cm inside the cloaca gently (Farghly et al. 2019; Erensoy et al. 2020a).

Welfare traits

A scale with 1 g precision (Jadever, JWQ-6 Digital Precision Scale, Northspring BizHub Industrial Building, Singapore) was used to determine individual live weights at 42 days of age. Welfare traits included FPD, HB, BB, and LP of all birds (10 males and 10 females from each group), and were determined using a visual scoring system between 0 and 3 scale (Welfare Quality 2009; Yamak et al. 2014; de Jong et al. 2020). In the determination of LP, chickens were classified clinically by holding their wings and the leg bone tarsal joint according to Leterrier and Nys (1992).

Meat quality traits

On day 43, three male and three female chickens in each pen were randomly selected and slaughtered after an 8-h fasting period. Semi-automated equipment was used for scalding (1 min at 56 °C), plucking, chilling (5 min at 1–5 °C), vent-opening, evisceration, and air-chilling (24 h at 4 °C). Following air-chilling, carcasses were cut into parts according
to standard methods (Sarica et al. 2014). Meat pH was measured at 3 points on the left thigh and left breast (model PC 510, Cyber Scan, Singapore), and meat color (L*: lightness, a*: redness, b*: yellowness) was evaluated at 3 points on the left thigh and left breast (Fanatico et al. 2005) using a colorimeter (Konica Minolta Cr-400).

Litter quality

Litter moisture content was determined at 43 days of the experiment. Litter samples were collected from three different points in each pen and they were mixed. One hundred grams of this mixture was dried at 60 °C for 48 h, and moisture content was measured according to Sarıca and Erensoy (2020).

Statistical analysis

This study was designed with a completely randomized design and a 2 × 2 factorial arrangement (feeding type × water temperature). The normality of the data was analyzed with the Shapiro-Wilk test. Panting rate, rectal temperature, and meat quality traits had normal distribution, and they were subjected to statistical analysis using the general linear model of the SPSS (version 25.0) program. The means were also tested at the level of $\alpha = 0.05$ by Duncan multiple comparison test. However, FPD, HB, BB, and LP traits had no normal distribution, so they were analyzed according to the Kruskal-Wallis and Mann-Whitney $U$ procedure. Interactions were explained with figures when statistically significant ($P < 0.05$). The standard error of the mean (SEM) for the traits with the normally distributed data type and the median, minimum, and maximum values were given in addition to the SEM for the non-normally distributed traits (Önder 2018).

Results

The effect of feeding type and water temperature on weekly rectal temperature change is given in Table 1. The treatments did not significantly affect the rectal temperatures of broilers at 4 and 6 weeks of age. However, at 5 weeks of age, rectal temperatures were significantly higher in IF chickens than AF, and in NW chickens compared to CW ($P < 0.05$); interaction effects were not significant.

Interaction effects were found significant on panting rate of chickens under heat stress at 4, 5, and 6 weeks of age ($P < 0.05$, Fig. 1). AF × CW broilers had significantly higher panting rates at all ages compared to the other groups ($P < 0.05$), and the other groups were found similar to each other. AF × CW chickens showed panting behavior as 71.5, 81.9, and 124.7 times per minute at 4, 5, and 6 weeks of age, respectively.

The effects of feeding type and water temperature on some welfare traits such as FPD, HB, BB, and LP are given in Table 2. The moisture content of CW chicken litter was significantly higher than that of NW chicken and was 24.3% and 18.0%, respectively ($P < 0.05$); interaction effects were not found significant. While FPD and LP were not affected by feeding type and water temperature treatments, interaction effects on HB and BB were found significant ($P < 0.05$, Table 2). HB and BB levels were the lowest in AF × NW, and the other groups were similar (Fig. 2).

The effects of feeding type and water temperature on color and pH traits of breast and thigh meat are given in Table 3. While main effects did not change to L*, a*, and b* values in breast meat, and L* and a* values in thigh meat, interactions significantly affected the b* value in the thigh ($P < 0.05$, Fig. 3). The b* value was the highest (4.41) in the thigh meat of the IF × CW chickens and the lowest (2.34) in AF × NW chickens ($P < 0.05$). Breast meat pH did not change significantly according to the treatments (Table 3). However, IF chickens (6.12) were lower than AF (6.20) and CW chickens (6.11) also showed lower thigh pH than NW (6.21) ($P < 0.05$, Table 3).

### Table 1 The effects of feeding type and water temperature on weekly rectal temperature

| Feeding type | Water temperature | Week 4 | Week 5 | Week 6 |
|--------------|-------------------|-------|--------|--------|
| AF NW        | 41.0              | 40.9  | 41.3   |
| AF CW        | 40.7              | 40.7  | 41.3   |
| IF NW        | 40.8              | 41.1  | 41.1   |
| IF CW        | 41.0              | 41.0  | 41.0   |
| SEM          | 0.05              | 0.05  | 0.07   |

Main effects

- **Feeding type**: $F = 0.843, P = 0.004, P = 0.118$
- **Water temp.**: $F = 0.560, P = 0.050, P = 0.916$
- **Interaction**: $F = 0.079, P = 0.375, P = 0.787$

### Table 2 The effects of feeding type and water temperature on some welfare traits

- **Moisture content**: CW > NW, $P < 0.05$
- **FPD, BB, LP**: Not affected
- **HB**: Lowest in AF × NW, $P < 0.05$

### Table 3 The effects of feeding type and water temperature on color and pH traits

- **b* value**: Highest in IF × CW, $P < 0.05$
- **pH**: Breast: Not significantly affected; Thigh: IG × NW, $P < 0.05$
Fig. 1 The effects of feeding type and water temperature on the weekly panting rate. AF, ad libitum feeding; IF, intermittent feeding; NW, normal water; CW, cold water. a,b The different letters among groups for each week were significantly different at \( p < 0.05 \) level using Mann-Whitney \( U \) test.

Table 2 The effects of feeding type and water temperature on welfare traits.1,2

| Feeding type | Water temperature | Litter moisture (%) | FPD | HB | BB | LP |
|--------------|-------------------|---------------------|-----|----|----|----|
| AF NW        | 18.4              | 0.03 (0.0–1)        | 0.37 (0.0–1)\(^b\) | 0.20 (0.0–1)\(^b\) | 0.07 (0.0–1) |
| AF CW        | 24.1              | 0.05 (0.0–1)        | 0.83 (1.0–2)\(^a\) | 0.58 (1.0–2)\(^a\) | 0.03 (0.0–1) |
| IF NW        | 18.5              | 0.00 (0.0–0)        | 0.67 (1.0–2)\(^a\) | 0.43 (0.0–1)\(^a\) | 0.10 (0.0–2) |
| IF CW        | 24.5              | 0.00 (0.0–0)        | 0.72 (1.0–1)\(^a\) | 0.49 (0.0–1)\(^a\) | 0.00 (0.0–0) |
| SEM          | 1.51              | 0.001               | 0.058 | 0.059 | 0.027 |

Main effects:

- **Feeding type**
  - 0.954 0.064 0.413 0.623 0.846
  - AF 20.9 0.04 (0.0–1) 0.63 (1.0–2) 0.41 (0.0–2) 0.04 (0.0–1)
  - IF 21.0 0.00 (0.0–0) 0.70 (1.0–2) 0.46 (0.0–1) 0.05 (0.0–2)
- **Water temp.**
  - 0.018 0.635 0.005 0.015 0.066
  - NW 18.0\(^b\) 0.01 (0.0–1) 0.54 (1.0–2) 0.33 (0.0–1) 0.09 (0.0–2)
  - CW 24.3\(^a\) 0.03 (0.0–1) 0.77 (1.0–2) 0.53 (1.0–2) 0.01 (0.0–1)
- **Interaction**
  - 0.954 0.299 0.002 0.023 0.300

1 Values in parentheses: (median: min–max)
2 AF, ad libitum feeding; IF, intermittent feeding; NW, normal water; CW, cold water; FPD, foot pad dermatitis; HB, hock burn; BB, breast burn; LP, leg problem; SEM, standard error of means. Differences among the FPD, HB, BB, and LP means were tested using Mann-Whitney \( U \) comparison test at 0.05 level. Means in a column without a common lowercase letter significantly differ (\( P \leq 0.05 \)).

Fig. 2 Interaction effects on hock burn (a) and breast burn (b) scores. AF, ad libitum feeding; IF, intermittent feeding; NW, normal water; CW, cold water. a,b The different letters among groups were significantly different at \( p < 0.05 \) level using Mann-Whitney \( U \) test.
Discussion

In the last half-century, a significant increase in meat yield has been mainly (85–90%) achieved by genetic selection for rapid growth traits, nutrition, and management practices (Havenstein et al. 2003; Erensoy et al. 2020b). However, the thermoregulation ability of broilers could not develop simultaneously with their growth traits. This has made metabolic heat dissipation, which has become more difficult as a result of increased body weight and feed intake, especially in the last 2–3 weeks of the production period, even more difficult in hot environmental conditions (Deeb et al. 2002; Zaboli et al. 2019). The presence of feathers and the absence of sweat glands in birds increase their sensitivity to high environmental temperatures (Lara and Rostagno 2013; Loyau et al. 2013) and negatively affect performance, welfare status, and meat quality traits (Aksit et al. 2006; Wang et al. 2013). In our study, IF and CW were given between 22 and 42 days of age to reduce the undesirable effects of heat stress on some welfare and meat quality traits in broilers.

Approximately 4.5–5 °C higher temperature and 9–10% lower relative humidity levels were determined in the period when heat stress was applied (11–17 h) compared to the hours that were not applied. In our study, although 6 h of IF treatment under heat stress conditions provided a numerical decrease in rectal temperature, this was not at a significant level. These results were found consistent with Farghly et al. (2018a) and inconsistent with the results of Özkan

Table 3 The effects of feeding type and water temperature on meat quality traits

| Feeding type | Water temperature | Breast meat | | | Thigh meat | | |
|--------------|------------------|-------------|---|---|-------------|---|---|
|              |                  | L*          | a* | b* | pH          | L* | a* | b* | pH |
| AF NW        | 57.86            | 1.52        | 2.82 | 5.91 | 58.84       | 4.29 | 3.59^a | 6.26 |
| AF CW        | 57.43            | 1.14        | 2.25 | 5.88 | 60.32       | 3.90 | 3.06^a | 6.12 |
| IF NW        | 57.99            | 1.20        | 2.51 | 5.92 | 60.34       | 3.55 | 2.34^b | 6.15 |
| IF CW        | 59.39            | 0.97        | 2.67 | 5.85 | 60.24       | 4.14 | 4.41^a | 6.08 |
| SEM          | 0.713            | 0.195       | 0.454 | 0.028 | 0.445       | 0.237 | 0.423 | 0.024 |

Main effects

Feeding type 0.306 0.863 0.386 0.932 0.257 0.462 0.929 0.045
AF 57.65 1.34 2.54 5.90 59.58 4.10 3.32 6.20^a
IF 58.70 1.09 2.59 5.89 60.31 3.85 3.37 6.12^b
Water temp. 0.634 0.282 0.750 0.221 0.274 0.767 0.207 0.005
NW 57.93 1.37 2.67 5.92 59.59 3.92 2.96 6.21^a
CW 58.42 1.06 2.46 5.87 60.30 4.02 3.73 6.11^b
Interaction 0.372 0.787 0.574 0.605 0.226 0.157 0.038 0.292

SEM 0.713 0.195 0.454 0.028 0.445 0.237 0.423 0.024

1 AF, ad libitum feeding; IF, intermittent feeding; NW, normal water; CW, cold water; L*, lightness; a*, redness; b*, yellowness; SEM, standard error of means. Differences among the means were tested using Duncan’s multiple comparison tests. Means in a column without a common lowercase letter significantly differ (P ≤ 0.05).

Fig. 3 Interaction effects on thigh meat yellowness (b*). AF, ad libitum feeding; IF, intermittent feeding; NW, normal water; CW, cold water. a,b The different letters among groups were significantly different at p < 0.05 level using Duncan’s means separation test.
et al. (2003) and Farghly et al. (2018b). Marai et al. (1999), Abioja et al. (2011), and Park et al. (2015) reported that giving cold water suppressed the increase in body temperature of broiler chickens. In addition, Fairchild and Ritz (2012) reported that drinking water at a lower temperature than the bird’s body temperature would help to dissipate the body temperature more easily. However, in the current study, CW treatment did not decrease the body temperature of broiler chickens at 6 weeks of age.

Panting is known to thermoregulate in many bird species (Steenfeldt et al. 2019). Syafwan et al. (2012) reported that rearing male broilers at 32 °C during the day and at 25 °C at night between 21 and 42 days did not change the panting rate. Abioja et al. (2011) and Farghly et al. (2018a) reported that CW intake reduces the panting rate in maintaining homeostasis in hot conditions in poultry. However, our study results showed that broilers in the AF × CW group under hot conditions showed the significantly highest panting rate at 4, 5, and 6 weeks of age in parallel. In previous studies, the effect of such an interaction on indicators of heat stress has not been tested before. While the panting rate is expected to decrease in broilers consuming CW (Farghly et al. 2018a), an unexpected effect occurred with AF × CW interaction. The fact that the body temperature of the AF chickens during heat stress hours (11–17 h) was 0.3 °C higher, although not at a significant level, may have caused more panting to remove metabolic heat from feed intake, in accordance with Farghly (2011). In addition, we speculated that consuming CW probably contributes to eliminating the undesirable effects of heat stress on broilers and is consistent with Fairchild and Ritz (2012).

Broilers consuming CW had worse litter quality than those consuming NW. In our previous study, which we conducted on the same chicken material, IF or CW did not affect water consumption (Erensöy et al. 2020a). Therefore, we speculated that the difference in water consumption did not cause deterioration in litter quality. However, CW chickens showed more panting behavior at 4, 5, and 6 weeks of age. Bessei (2006) stated that the duration of sitting or lying down (resting) behaviors increased with advancing age in broilers. In addition, body weight increase as the growth period progress, so the floor area is almost completely covered by birds, making it difficult to ventilate the litter surface (Bessei 2006). Although behaviors were not examined in our study, it is speculated that activity decreases with advancing age, possibly due to panting behavior, and that chickens consuming CW have more contact with relatively high moisture litter. Conversely, chickens in the AF × NW group showed less HB and BB. Water temperature treatment rather than feeding type seems more effective in the interaction effects for HB and BB. In our study, more prolonged contact of the hock and breast with the litter increased the severity of HB and BB, consistent with Mench (2002) and Allain et al. (2009). However, the fact that FPD and LP were not significantly affected by this situation was not compatible with the general literature (Shepherd and Fairchild 2010; Cengiz et al. 2011; Mello et al. 2015; Dunlop et al. 2016). In our study, both FPD and LP varied within minimal limits, and FPD was seen in only 3 chickens and LP in 5 chickens among all broilers (data not shown).

Pre-slaughter stress factors such as heat stress, fasting, handling, and water deprivation may affect meat quality (Mota-Rojas et al. 2006). One of our hypotheses for this study was that the undesirable effects of heat stress on meat quality could be reduced by management practices such as IF and CW treatments, but the results appeared to support our hypothesis partially. IF treatment decreased the panting rate compared to AF, but unexpectedly, the highest panting was observed in AF × CW broilers for all age periods. Panting behavior is a physiological response of birds to maintain thermal homeostasis under heat stress conditions, provide heat dissipation through respiration, and regulate body temperature (Yahav et al. 2005). The increase in the panting rate decreases the H+ ion concentration in the blood plasma, causing a decrease in pH (respiratory alkalosis), and it becomes difficult to maintain body temperature balance (Sandercock et al. 2006; Zaboli et al. 2019). This mechanism results in a faster pH drop and lower ultimate pH in breast meat of broiler. PSE (pale, soft, and exudative) syndrome develops due to lower pH in breast meat, higher lightness (L*), and lower redness (a*) and yellowness (b*) (Petracci et al. 2004; Akşit et al. 2006). However, in our study, IF and CW treatments were insufficient to significantly change the ultimate pH and color traits of breast meat compared to consuming AF and NW chickens. These results were consistent with Lippens et al.’s (2000) report that IF does not affect the pH and color traits of breast meat. However, IF and CW treatments significantly decreased the ultimate pH of the thigh meat in broiler chickens. We speculated that CW intake increases the panting rate and contributes to the decrease in the ultimate pH of the thigh meat. In addition, the yellowness (b*) of thigh meat was also found highest in IF × CW broilers. Consistent with Lu et al. (2007), a further decrease in thigh meat pH of broilers in the CW group probably caused more yellowness (b*).

We concluded that management practices such as IF and CW in fast-growing broilers could not completely reduce the undesirable effects of heat stress on some welfare and meat quality traits, and in some cases, even caused more negativity. When AF broilers consumed CW, the panting rate unexpectedly increased, and the severity of HB and BB increased. While IF and CW treatments did not affect the
quality traits of breast meat, they decreased the ultimate pH value and increased the yellowness (b*) in thigh meat.

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Author contribution All listed authors have made substantial contributions to the research design, analysis, or interpretation of data, and drafting the manuscript. All authors have approved the submitted version.

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Data availability Not applicable.

Code availability Data were analyzed using SPSS (version 25.0).

Declarations

Ethics approval All procedures for the rearing, management, and slaughtering were approved by the Ondokuz Mayis University Ethical Committee for Experimental Animals (30.06.2017; 2017/31).

Conflict of interest The authors declare no competing interests.

References

Abioja, M.O., Osinowo, O.A., Smith, O.F., Eruvbetine, D., and Abiona, J.A., 2011. Evaluation of cold water and vitamin C on broiler growth during hot-dry season in SW Nigeria, Archives de Zootecnie, 60(232), 1095-1103.

Akşit, M., Yalcin, S., Özkan, S., Metin, K., and Özdemir, D., 2006. Effects of temperature during rearing and crating on stress parameters and meat quality of broilers, Poultry Science, 85(11), 1867-1874. https://doi.org/10.1093/ps/85.11.1867.

Allain, V., Mirabito, L., Arnould, C., Colas, M., Le Bouquin, S., Lupo, C., and Michel, V., 2009. Skin lesions in broiler chickens measured at the slaughterhouse: relationships between lesions and between their prevalence and rearing factors, British Poultry Science, 50(4), 407-417. https://doi.org/10.1080/00071660903110901.

Berri, C., Wacrenier, N., Millet, N., and Le Bihan-Duval, E., 2001. Effect of selection for improved body composition on muscle and meat characteristics of broilers from experimental and commercial lines, Poultry Science, 80(7), 833-838. https://doi.org/10.1093/ps/80.7.833.

Bessei, W., 2006. Welfare of broilers: a review, World’s Poultry Science Journal, 62(3), 455-466. https://doi.org/10.1017/S0043933906001085.

Cahaner, A., Deeb, N., and Gutman, M., 1993. Effects of the plumage-reducing naked neck (Na) gene on the performance of fast-growing broilers at normal and high ambient temperatures, Poultry Science, 72(5), 767-775. https://doi.org/10.3382/ps.0720767.

Cengiz, Ö., Hess, J.B., and Bilgili, S.F., 2011. Effect of bedding type and transient wetness on footpad dermatitis in broiler chickens, Journal of Applied Poultry Research, 20(4), 554-560. https://doi.org/10.3382/japr.2011-00368.

Dawkins, M.S., Donnelly, C.A., and Jones, T.A., 2004. Chicken welfare is influenced more by housing conditions than by stocking density, Nature, 427 (6972), 342-344. https://doi.org/10.1038/ nature02226.

de Jong, I.C., van Hattum, T., van Riel, J.W., De Baere, K., Kempen, I., Cardinaels, S., and Gunnink, H., 2020. Effects of on-farm and traditional hatching on welfare, health, and performance of broiler chickens, Poultry Science, 99(10), 4662-4671. https://doi.org/10.3382/ps.2020.06.052.

Deeb, N., Shlosberg, A., and Cahaner, A., 2002. Genotype-by-environment interaction with broiler genotypes differing in growth rate. 4. Association between responses to heat stress and to cold-induced ascesites, Poultry Science, 81(10), 1454-1462. https://doi.org/10.1093/ps/81.10.1454.

Dunlop, M.W., Moss, A.F., Groves, P.J., Wilkinson, S.J., Stuetz, R.M., and Selle, P.H., 2016. The multidimensional causal factors of ‘wet litter’ in chicken-meat production, Science of the Total Environment, 562, 766-776. https://doi.org/10.1016/j.scitotenv.2016.03.147.

El Rammouz, R., Berri, C., Le Bihan-Duval, E., Babile, R., and Fernandez, X., 2004. Breed differences in the biochemical determinism of ultimate pH in breast muscles of broiler chickens—a key role of AMP deaminase?, Poultry Science, 83(8), 1445-1451. https://doi.org/10.1093/ps.83.8.1445.

Erensoy, K., Noubandiguim, M., Sarca, M., and Aslan, R., 2020a. The effect of intermittent feeding and cold water on performance and carcass traits of broilers reared under daily heat stress, Australasian Journal of Animal Sciences, 33(12), 2031. https://doi.org/10.5713/ajas.19.0980.

Erensoy, K., Noubandiguim, M., Cilavdaroglu, E., Sarca, M., and Yamak, U.S., 2020b. Correlations between Breast Yield and Morphometric Traits in Broiler Pure Lines, Brazilian Journal of Poultry Science, 22(1). https://doi.org/10.1590/1806-9061-2019-1148.

Fairchild, B.D., and Ritz, C.W., 2012. Poultry drinking water primer, UGA Cooperative Extension Bulletin, 1301.

Fanatico, A.C., Cavitt, L.C., Pillai, P.B., Emmert, J.L., and Owens, C.M., 2005. Evaluation of slower-growing broiler genotypes grown with and without outdoor access: meat quality, Poultry Science, 84(11), 1785-1790. https://doi.org/10.1093/ps/84.11.1785.

Farghly, M.F.A., 2011. Changing lighting and feeding time to alleviate the deleterious effect of hot Assiut summer on performance of Japanese quail, Egyptian Journal of Animal Production, 48, 315-320.

Farghly, M.F.A., Abd El-Hack, M.E., Alagawany, M., Saadeldin, I.M., and Swelum, A.A., 2018a. Wet feed and cold water as heat stress modulators in growing Muscovy ducklings, Poultry Science, 97(5), 1588-1594. https://doi.org/10.3382/ps/pey006.

Farghly, M.F., Mahroze, K.M., Galal, A.E., Ali, R.M., Ahmad, E.A., Rehman, Z.U., Ullah, Z., and Ding, C., 2018b. Implementation of different feed withdrawal times and water temperatures in managing turkeys during heat stress, Poultry Science, 97(9), 3076-3084. https://doi.org/10.3382/ps/pey173.

Farghly, M.F., Mahroze, K.M., Ahmad, E.A., Rehman, Z.U., and Yu, S., 2019. Implementation of different feeding regimes and flashing light in broiler chicks, Poultry Science, 98(5), 2034-2042. https://doi.org/10.3382/ps/pey577.

Haslam, S.M., Knowles, T.G., Brown, S.N., Wilkins, L.J., Kestin, S.C., Warriss, P.D., and Nicol, C.J., 2007. Factors affecting the prevalence of foot pad dermatitis, hock burn and breast burn in broiler chicken, British Poultry Science, 48(3), 264-275. https://doi.org/10.1080/00071660701571341.

Havenstein, G.B., Ferket, P.R., and Qureshi, M.A., 2003. Growth, livability, and feed conversion of 1957 versus 2001 broilers when...
fled representative 1957 and 2001 broiler diets, Poultry Science, 82(10), 1500-1508. https://doi.org/10.1093/ps/82.10.1500.

Hristov, A.N., Degaetao, A.T., Rotz, C.A., Hoberg, E., Skinner, R.H., Felix, T., Li, H., Patterson, P.H., Roth, G., Hall, M., Ott, T.L., Baumgard, L.H., Staniar, W., Hulet, R.M., Dell, C.J., Brito, A.F., and Hollinger, D.Y., 2018. Climate change effects on livestock in the Northeast US and strategies for adaptation, Climatic Change, 146(1), 33-45. https://doi.org/10.1007/s10584-017-2023-z.

Lara, L.J., and Rostagno, M.H., 2013. Impact of heat stress on poultry production, Animals, 3(2), 356-369. https://doi.org/10.3390/ani3020356.

Le Bihan-Duval, E., Millot, N., and Remignon, H., 1999. Broiler meat quality: effect of selection for increased carcass quality and estimates of genetic parameters, Poultry Science, 78(6), 822-826. https://doi.org/10.1093/ps/78.6.822.

Le Bihan-Duval, E., Debut, M., Berri, C.M., Sellier, N., Santé-Lhou, V., Jégo, Y., and Beaumont, C., 2008. Chicken meat quality: genetic variability and relationship with growth and muscle characteristics, BMC genetics, 9(1), 1-6. https://doi.org/10.1186/1471-2156-9-53.

Leterrier, C., and Nys, Y., 1992. Composition, cortical structure and mechanical properties of chicken tibiotarsi: effect of growth rate, British Poultry Science, 33(5), 925-939. https://doi.org/10.1080/00071669208417536.

Lippens, M., Room, G., De Groote, G., and Decuyper, E., 2000. Early and temporary quantitative food restriction of broiler chickens. 1. Effects on performance characteristics, mortality and meat quality. British Poultry Science, 41(3), 343-354. https://doi.org/10.1080/000713654926.

Loyau, T., Berri, C., Bedrani, L., Metayer-Coustard, S., Praud, C., Duclos, M.J., Tesserault, S., Rideau, N., Everaert, N., Yahav, N., Sahraei, M., and Collin, A., 2013. Thermal manipulation of the embryo modifies the physiology and body composition of broiler chickens reared in floor pens without affecting breast meat processing quality, Journal of Animal Science, 91(8), 3674-3685. https://doi.org/10.1093/jas/ksr175.

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. https://doi.org/10.1093/ps/86.6.1059.

Marai, I.F.M., Ayyat, M.S., Gabr, H.A., and Abd El-Monem, U.M., 1999. Growth performance, some blood metabolites and carcass traits of New Zealand White broiler male rabbits as affected by heat stress and its alleviation, under Egyptian conditions, Options Mediterraneennes, 41, 35-42.

Mello, J., Boiago, M., Giampietro-Ganeco, A., Berton, M., Vieira, L., Souza, R., Ferrari, F., and Borba, H., 2015. Periods of heat stress during the growing affects negatively the performance and carcass yield of broilers, Archivos de Zootecnia, 64, 339-345.

Mench, J.A., 2002. Broiler breeders: feed restriction and welfare, World’s Poultry Science Journal, 58(1), 23-29. https://doi.org/10.1079/WPS200020004.

Mota-Rojas, D., Becerril, M., Lemus, C., Sánchez, P., González, M., Olmos, S.A., Ramirez, R., and Alonso-Spilsbury, M., 2006. Effects of mid-summer transport duration on pre-and post-slaughter performance and pork quality in Mexico, Meat Science, 73(3), 404-412. https://doi.org/10.1016/j.meatsci.2005.11.012.

Noubandiguim, M., Erensoy, K., and Sarica, M., 2021. Feather growth, bodyweight and body temperature in broiler lines with different feathering rates, South African Journal of Animal Science, 51(1). https://doi.org/10.4314/sajas.v51i11.10.

Önder, H., 2018. Nonparametric statistical methods used in biological experiments, Black Sea Journal of Engineering and Science, 1(1), 1-6.

Özkan, S., Akbaş, Y., Altan, Ö., Altan, A., Ayhan, V., and Özkan, K., 2003. The effect of short-term fasting on performance traits and rectal temperature of broilers during the summer season, British Poultry Science, 44(1), 88-95. https://doi.org/10.1080/00071668.2012.745927.
Welfare Quality, 2009. The Overall On-farm Animal Welfare Score, http://www.welfarequalitynetwork.net/network/45848/70/40, Accessed on 19.06.2021.
Yahav, S., Shinder, D., Tanny, J., and Cohen, S., 2005. Sensible heat loss: the broiler’s paradox, World’s Poultry Science Journal, 61(3), 419-434. https://doi.org/10.1079/WPS200453
Yamak, U.S., Sarica, M., and Boz, M.A., 2014. Comparing slow-growing chickens produced by two-and three-way crossings with commercial genotypes. 1. Growth and carcass traits, European Poultry Science, 78. https://doi.org/10.1399/eps.2014.XX.
Zaboli, G., Huang, X., Feng, X., and Ahn, D.U., 2019. How can heat stress affect chicken meat quality?—a review, Poultry Science, 98(3), 1551-1556. https://doi.org/10.3382/ps/pey399.

Zhang, Z.Y., Jia, G.Q., Zuo, J.J., Zhang, Y., Lei, J., Ren, L., and Feng, D.Y., 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. https://doi.org/10.3382/ps.2012-02255.

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