Influence of stocking density on welfare indices of broilers

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Abstract

The current study was conducted to identify the influence of short-term (five days) high stocking density (SD) on broilers’ welfare by assessing several thermophysiological parameters in 32 birds of 43 days of age Ross male broiler chickens. Based on broiler’s body weight, broilers were randomly allotted into two SD rates; control (26.5 kg/m²) or high (45.0 kg/m²). It appears evident that placing broilers at high SD as 45.0 kg/m² had manifested noticeable impacts on their thermophysiological responses. This conclusion was demonstrated by the existence of results of the current study showed a major displacements in broilers’ homeothermic status, high SD broilers experienced pronounced elevations of their body temperatures as well as head, body and shank surface temperatures over the control SD broilers. Additionally, this was further emphasized by the noticeable displacements of body internal, external and total thermal gradients as well as heat loss index of high SD broilers compared to the control broilers. Based on the presented evidences, short-term high SD markedly increased broilers stress and jeopardized their welfare. Measuring broilers’ thermophysiological responses under different rates of SD can be adapted to assess their welfare.

Introduction

There is a growing body of evidence that modern broiler chickens performed better at low stocking density (SD) (Dozier et al., 2005, 2006; Chmelničná and Solčianska, 2007; Mtieleni et al., 2007; Škrbic et al., 2009). Unfortunately, poultry producers aimed to maximize the kilograms of chicken produced per square meter of space in order to achieve a satisfactory economic return. Consequently, several studies had been conducted to study the effect of different SD on broilers performance. Due to the limited physical access to feeders as well as the competition between birds on feed, high rates of SD had been observed to drastically reduce broilers growth rate, feed consumption, feed conversion ratio, and their carcass quality, as well as increase litter moisture and incidences of footpad and thighs lesions (Shanawany, 1988; Puron et al., 1995; Dozier et al., 2005, 2006; Chmelničná and Solčianska, 2007; Mtieleni et al., 2007; Škrbic et al., 2009).

Apart from these intensive effects, a considerable concern was expressed regarding the influence of SD on broilers welfare and abundant research works in the past 10 years had aimed to identify the impact of different rates of SD on broilers welfare (Hall, 2001; Algers and Berg, 2004; Dawkins et al., 2004; Thomas et al., 2004; Jones et al., 2005; Bessei 2006; Ravindran et al., 2006; Thaxter et al., 2006; Buijs et al., 2009). Collectively, these studies showed that SD had manifested noticeable displacements on several physiological, behavioral, and health parameters of broiler chickens. Therefore, the National Chicken Council (2011) has established a voluntary animal welfare guideline and audit checklist for broilers companies to follow. This guideline listed a maximum limit of SD based on broilers final body weight, where it ranged from 31.8 kg/m² for light broilers to 41.6 kg/m² for roasters. Moreover, the guideline states that: Bird welfare at different stocking densities will depend on access to feeders and drinkers, lighting program, type of housing, ventilation system, feeder/drinker equipment, litter management, and husbandry. Thereby, optimal environmental conditions and thermal comfort must be provided for broilers to maintain constant body temperature and to achieve their genetic potential for superior growth while maintaining their welfare (Feddes et al., 2002; Yahav et al., 2004; Cangar et al., 2008; Marelli et al., 2012).

In comparison with other homeothermic experimental animal models, highly productive agricultural fowl, such as chicken and turkeys, differ to some extent in their abilities to maintain homeostasis in presence of severe environmental challenges due to their enhanced genetic development for economically important production trait without parallel increases in the functional efficiency of their thermophysiological systems (Brake and Yahav, 2012). Few researchers have specifically addressed how SD may affect broilers’ physiological responses, and thus their welfare (Dawkins et al., 2004; Jones et al., 2005; Buijs et al., 2009; Beloor et al., 2010); however, it is still unclear if SD has an impact on broilers’ thermophysiology. An interesting approach to study broilers welfare under different rates of SD would be through monitoring their thermophysiological responses. Accordingly, the current study was undertaken to identify the influence of short-term SD on several thermophysiological parameters of Ross broiler chickens.

Materials and methods

Animals, managements and treatments

Thirty two birds of 43 days old Ross 308 male broiler chickens were obtained (Al-Wadi Poultry Farm Co., Riyadh, Saudi Arabia) and reared in electrically heated battery brooders with raised wire floors under a controlled environment (average temperature was 24.15°C ±0.28) at the poultry house (Department of Animal Production, College of Food and Agriculture Sciences, King Saud University, Riyadh, Saudi Arabia). Broilers were maintained throughout the study at 24 hours light schedule in a four deck cages system. Each cage had a dimension of 50 cm in...
length, 60 cm in width, and 36 cm in depth and was fitted with automatic nipple drinking system and traditional galvanized steel tough. Feed and water were provided ad libitum. A remix diet (starter and finisher diets) was offered for broilers (Tables 1 and 2). Based on broilers’ body weight at 43 days, birds were randomly allotted into two rates of SD: control (26.5 kg/m²) or high (45.0 kg/m²), corresponded to 0.10 and 0.06 m²/bird, respectively. The control group had three birds per cage for a total of 12 birds while the high group had five birds for a total of 20 birds (Figure 1). Short-term (five days) stocking was applied in the current study (43 to 48 days of age). It is worthwhile to point out, however, that broilers were observed twice a day by a researcher for body injuries. Housing protocols, handling of animals as well as study design were pre-approved by the faculty ethics committee of King Saud University.

Environmental measurements

Ambient temperature (Tₐ) was continuously recorded during the five experimental days at 3 hours interval using 2 data loggers (HOBBO Pro Series data logger, Model H08-032-08, ONSET Co., Cape Cod, MA, USA) placed inside the cage system and mounted at a height of approximately 2 m from the ground and away from direct sources of water. A special data logging software (BoxCar Pro 4, ONSET Co.) was utilized for programming the loggers and for data analysis. The obtained Tₐ data were analyzed for the following parameters; mesor (mean level or midline estimating statistic of rhythm), zenith (rhythm’s maximum value), nadir (rhythm’s minimum value), as well as the thermal load (zenith – nadir) in a 24 h interval period.

Thermophysiological measurements

Body (cloacal) temperatures (Tₚ) as well as total, head, body, and shank surface temperatures (Tₛ) were determined twice (at pre-stocking as well as after five days post-stocking) between 10:00 and 12:00 h in all broilers. Measurements were recorded using a pre-calibrated digital thermometer (ARTSANA, Grandate, CO, Italy) measure to the nearest 0.1°C for Tₚ. Meanwhile, left side thermograms (infra-red thermographic images) for broilers’ total body surface were obtained using a forward looking and automatically calibrating infrared camera (VisIR-Ti200 infrared vision camera, Thermoteknix Systems Ltd., Cambridge, UK) placed perpendicular and approximately 50 cm away from bird’s surface (Figure 2). The camera was equipped with 25° lens, 1.3 M pixel visible camera, LCD touch screen, and possesses a 7.5-13 m spectral range as well as a precision of ±0.10°C. Thermograms were stored after capturing inside a 250 MB internal memory, readout and analyzed using a special thermograms analysis program (TherMonitor, Thermoteknix Systems Ltd.). Obtained thermograms were analyzed by defining areas circumscribed by hand with the software polygon function. The software, thereafter, calculated the average, minimum, and maximum Tₛ within the defined areas. For all thermograms, the rainbow color scheme was chosen. Additionally, the distance between the chick and the camera as well as emissivity of animal body was supplied for the camera to compensate for the effects of different radiation sources. It is worth mentioning that similar body emissivity (0.97; Monteith and Unsworth, 1990) was used for all thermograms, and the recording time between chicks was kept to minimum. Illustrations of thermograms for broilers belonging to different SD rates are presented in Figure 3.

Several formulas: [body temperature (Tₚ) - surface temperature (Tₛ)], [surface temperature (Tₛ) - ambient temperature (Tₐ)], and [body temperature (Tₚ) - ambient temperature (Tₐ)], were used to estimate the internal (physiological) thermal gradients, the external (physical) thermal gradients, and the total thermal gradients, respectively (Richards,

| Table 1. Dietary ingredients of the remixed diet used in the current study. |
|--------------------------|--------------------------|
| Ingredients, g/kg | |
| Corn | 564.0 |
| Soybean meal | 341.0 |
| Palm oil | 59.0 |
| Dicalcium phosphate | 20.0 |
| Ground limestone | 7.00 |
| DL-methionine | 1.00 |
| Salt | 3.00 |
| Vitamin premix* | 2.50 |
| Trace mineral mix$ | 0.50 |
| Choline chloride 60 | 0.50 |
| Sodium bicarbonate | 1.50 |

*Vitamin is supplied in the following per kg of diet: retinyl acetate, 3.41 mg; cholecalciferol, 0.07 mg; DL-α-tocopheryl acetate, 27.5 mg; menadione sodium bisulphate, 6 mg; riboflavin, 7.7 mg; niacin, 44 mg; pantothenic acid, 11 mg; cyanocobalamin, 0.02; choline, 496 mg; folic acid, 1.32 mg; pyridoxine HCl, 1.42 mg; thiamine mononitrate, 2.16 mg; D-ribose, 0.11 mg. $Mineral-mix is supplied in the following per kg of diet: manganese, 67 mg; zinc, 54 mg; copper, 2 mg; iodine, 0.5 mg; iron, 75 mg; selenium, 0.2 mg.

| Table 2. Calculated analysis of the experimental diets. |
|--------------------------|--------------------------|
| Calculated analysis                  |
| ME, kcal/kg | 3150 |
| Crude protein, % | 21.0 |
| Lysine, % | 1.10 |
| Methionine, % | 0.40 |
| Threonine, % | 0.81 |
| Total sulfur amino acids, % | 0.75 |
| Calcium, % | 0.50 |
| Non phytate phosphorus, % | 0.40 |

ME, metabolizable energy.

Figure 1. Schematic representation of broiler allocation. All birds (n=32) were randomly allotted into 2 stoking densities; control (n=12 or 26.5 kg/m²) and high (n=20 or 45.0 kg/m²) density rates.

Figure 2. Pictures of VisIR thermal imaging camera used to measure broilers’ total body surface (adopted from the manufacture website at: http://www.thermoteknix.com).

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Furthermore, the ratio \([T_s-T_a / T_b-T_s]\) was applied to measure the heat loss index (HLI) of broilers (Romanovsky and Blatteis, 1996).

**Statistical analysis**

Statistical analysis was performed using the Statistical Analysis System Program/Software (SAS, 2004). Two treatments were replicated four times in a randomized complete block design to eliminate the effect of cage location. Means for measurements showing significant differences in ANOVA were tested using the PDIFF option. Means ± standard error of the mean (SEM) are presented in the tables, unless otherwise specified and differences were considered statistically significant at P<0.05.

**Results**

Results revealed no differences (P>0.05) in the measured daily mesor, zenith, nadir and thermal load values of \(T_a\). The recorded daily mesor value of \(T_a\) during the present study was 24.48°C±0.24 (standard deviation). Meanwhile, overall mean of daily \(T_a\) thermal loads was 0.55°C±0.13 (standard deviation), which is a reasonable approximation of the uniform distribution of the environmental conditions throughout the study.

In the current study, no differences (P>0.05) in the measured thermophysiological parameters were observed among broilers at the pre-stocking period. Alternatively, measurements were influenced by the rate of SD, where stocking broilers at high SD rates as 45.0 kg/m² had a clear impact on their thermophysiological responses (Table 3). Broilers of high SD rate experienced a pronounced (P<0.001) elevations in their overall means of \(T_b\) as well as head \(T_s\), body \(T_s\), and shank \(T_s\) over the control broilers (Table 3). Moreover, body thermal gradients showed a significant (P<0.001) displacements in high SD rate broilers compared to control broilers (Figure 4A). Internal thermal gradients \([T_b-T_s]\) were decreased (P<0.0001) from 7.82°C±0.05 in broilers of control SD to 6.61°C±0.05 in broilers of high SD. Meanwhile, external thermal gradients \([T_s-T_a]\) were increased (P<0.001) from 8.06°C±0.04 in broilers of control SD to 9.77°C±0.05 in broilers of high SD. Taken together, high SD broilers exhibited a significant (P<0.001) elevations in their total thermal gradients \([T_b-T_s]\) over the control broilers. Likewise, overall means of HLI showed (P<0.001) higher values in high SD broilers over the control broilers (Figure 4B).

**Discussion**

In the current study, when broilers of high SD rate were compared to their counterparts of control SD, high SD broilers exhibited higher \(T_b\). Stocking conditions seems to resemble the huddling behaviour of broilers, applied under low environmental condition to minimized their body heat loss, except that broilers are forced to huddle when maintained under high rates of SD. Broilers of high SD rate, created an impediment for dissipation of their body heat and consequently increased their body heat content as reflected by high \(T_b\). Therefore, improving the microenvironment adjacent to broilers has to be on the top priority of management policies. This approach is often difficult, however, since the ventilation systems are poorly functioning in mixing the mesoenvironment of the poultry house with broilers' microenvironment (Brake and Yahav, 2012). Thus, it is clear that much work is required in order to fully exploit this approach.

**Table 3. Body and surface temperatures of broilers subjected to two different rates of stocking density.**

|                      | Control (26.5 kg/m²) | High (45.0 kg/m²) | SEM     | P value |
|----------------------|----------------------|-------------------|---------|---------|
| \(T_b\), °C          | 40.36b               | 40.86a            | 0.03    | ***     |
| Total \(T_s\), °C    | 32.54b               | 34.25a            | 0.04    | ***     |
| Head \(T_s\), °C     | 34.08b               | 35.79a            | 0.14    | ***     |
| Body \(T_s\), °C     | 35.40b               | 36.34a            | 0.07    | ***     |
| Shank \(T_s\), °C    | 35.15b               | 36.24a            | 0.07    | ***     |

\(T_b\): body temperature; \(T_s\): surface temperature. *Mean values within the same row bearing different superscripts are significantly different. ***P<0.001.*
The true nature that broilers of high SD rate had higher $T_r$ reinforces the basic axis that increasing SD rate would possess an impact on broilers’ thermoregulatory system. It is definitive, therefore, that high SD rate broilers must dissipate their body heat to maintain a constant body temperature (Yahav and Giloh, 2010). In fact, noticeable divergences in several thermophysiological measurements were noticed in high SD rate broilers over the control broilers.

In the current study, broilers of high SD have demonstrated higher total $T_s$ (4.99%) compared to broilers in control SD (Table 3). Physiologically, $T_s$ is an indication of the amount of invisible heat energy emitted. Infrared cameras measure the amount of invisible heat energy emitted by body surfaces, convert them into temperatures, and then produce thermal images (McCafferty et al., 2011). The adoption of infrared thermography in biological sciences has created a simplified method for evaluation of $T_s$ (and its contribution to sensible heat loss) as well as identifying radiant temperatures with distinct and precision values (Cangar et al., 2008; Bouzida et al., 2009; Naas et al., 2010). In general, $T_s$ depend on the interaction between body heat, body insulation, surface blood circulation, and $T_b$ (Monteith and Unsworth, 1990). Regarding body insulation, heat flow is resisted by 3 body insulators. Figure 5 shows a diagrammatic illustration of how body heat flow is resisted by broilers’ body thermal insulations. Body internal tissues are poor conductors. Therefore, body heat is mainly transferred through convection way to blood circulations to be dissipated at skin surface. Meanwhile, heat flow between skin surface and the outer edge of the feathers is resisted by feather insulation. Moreover, due to the high isolative value of still air that entrapped among the feathers, boundary insulation resists the heat flux from the feathers to the surrounding environment. According to Richards (1973), however, feather and boundary insulations were combined into surface insulation. Under high SD rate, we observed that broilers movements were almost impaired, which might indicate an increase in surface insulation due to the undistruptive still air layer. Consequently, this lack of movements further confirmed the previous discussion where broilers maintained under high SD rate had experienced intense microunvironmental conditions over the control broilers. This came in accordance with the findings of Hall (2001), Dawkins et al., (2004), and Dozier et al., (2006), where they all observed a reduction of broilers’ welfare in SD rates higher than 35 kg/m². Therefore, these results point out a marked necessity to active emergency husbandry practices under high SD rates. From a thermal point of view, heat flows from warm to cool environments. Therefore, it is definitive that a thermal gradient exist when two interacting environments had different temperatures. According to Curtis (1983), body thermal gradients could be divided into; internal thermal gradients from body core to the surface, and into external thermal gradients from body surface to the surrounding environment. In the current study, the internal thermal gradient was measured using the equation $[T_b-T_s]$, while external thermal gradient was measured as $[T_b-T_r]$. However, the approximation $[T_b-T_s]$ was used to measure the total thermal gradient from the core to the environment. Under conditions of thermoneutrality, these gradients drive the heat flux from the body to its environment, but in extreme conditions heat flows from external environment to the animal body. In the current study, body thermal gradients manifested a substantial percentage changes in high SD rate broilers compared to control broilers, where $T_b-T_s$ values were decreased (-18.3%) while $T_b-T_r$ values were increased (17.5%) in broilers of high SD rate over the control broilers. Because the common player in the two equations is the $T_b$, the high percentage changes (4.99%) in $T_s$, of high SD rate broilers led to decrease their calculated $T_b-T_s$ values and increase their $T_b-T_r$ values. To eliminate the effect of $T_b$, however, the HLI ratio was used. In parallel with body thermal gradients, broilers of high SD rate demonstrated higher percentage changes (18.0%) in comparison to broilers of control SD rate. Collectively, these results imply that the distance between body core and the surrounding environment have to decrease under high SD rate; primarily, to elevate $T_r$ and subsequently, to facilitate more efficient body heat dissipation through sensible and latent heat loss mechanisms.

Different body regions (i.e., thermal windows) play an important role in shifting blood distribution to create a thermal gradient between the body and environment, resulting in more heat loss by radiation and convection ways (Shinder et al., 2007; Brake and Yahav, 2012). In the current study, head and shank $T_s$ of broilers belong to the 2 SD had exhibited higher temperature values than body $T_b$. Nevertheless, body $T_s$ showed more percentage changes (7.4%) than head $T_s$ (4.77%) and shank $T_s$ (3.27%). These findings are in agreement with previous studies (Cangar et al., 2008; Tattersall et al., 2008), where body featherless areas (eye, ear, bill, wing bar and shank) presented higher temperatures than the areas of the body covered by feathers (neck, back cape, flight feathers, breast, thigh, drumstick, and tail). Thus, pertained to continuous blood flow to the featherless areas, their $T_s$ were kept nearly constant at different $T_b$, while $T_s$ of their feather areas exhibited more changes as $T_b$ is change. Nevertheless, using different $T_b$ to identify which body thermal window is activated the most in broiler chickens under different SD rates remains to be considered in future studies.

Thermal homeokinesis is a steady state where body temperature is relatively maintained constant despite any fluctuating of the external environment (IUPS Thermal Commission, 2001). According to this definition, it appears that broilers maintained under high SD rate had experienced more intense environmental conditions than their twins under the control SD rate. This was in concordant with previous studies (Dawkins et al., 2004; Jones et al., 2005), where controlling the environment was demonstrated to be a key factor in improving broilers’ welfare. Throughout the current study, we assumed that the surrounding environment had the same $T_b$ (=24.48°C), a feasible assumption because

Figure 5. Diagrammatic illustration of how body heat flow (shown by the horizontal arrows) is resisted by broilers’ body thermal insulations (shown by the vertical arrows).
thermal load of daily $T_d$ did not differ significantly throughout the study. Thus, error is probably small because of this assumption. Moreover, based on the definition of the thermoneutral zone for broilers (Weathers, 1981; Meltzer, 1983; Brake and Yahav, 2012), we also assumed that current observations were conducted within the comfort zone of broiler chickens. Given these considerations, it appears to be reasonable to attribute the noticed differences in broilers thermophysiological responses to the stocking conditions rather than to the environmental temperature.

Conclusions

Based on the presented evidences, short-term period of high SD for merely five days had increased broilers stress and jeopardize their welfare. Measuring the thermophysiological responses under different rates of SD can be adapted in assessing broilers’ welfare. However, further studies are required to validate our results using different densities and longer period of stocking as well as utilizing other parameters (such as respiratory rate, heart rate, cutaneous evaporative water and hematic parameters).

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