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Thermal acclimation of broiler birds by intermittent heat exposure

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ABSTRACT

Heat stress impairs the performance of broilers which increases the economic losses. Effect of duration of heat exposure on performance and acclimatory responses in broiler birds was investigated. At 21 d of age 160 Hubbard birds (80 males + 80 females) were equally distributed into 5 treatments (T). The T1, T2, T3 and T4 were acclimated by daily exposure to heat (38 ± 1 °C, 62 ± 2% RH) for 1, 2, 3 and 4 h/d, respectively, for 14 d. T0 was the non-acclimated control (kept at 22 ± 2 °C, 65 ± 2% RH). At 36 d of age the thermotolerance of all birds was evaluated under simulated heat wave conditions by exposing them to an acute heat stress (43 ± 1 °C, 55 ± 3% RH) for 4 h. Body weight (BW), average daily gain (ADG) and average daily feed intake (ADFI) were not affected in T2 and T3, while T3 and T4 showed significant reductions in BW, ADG and ADFI compared to the control. Daily changes in ADFI/kg of metabolic BW (ADFI/$BW^{0.75}$), rectal temperature (Tr), rate of increase in rectal temperature (RITr) and evaporative water loss (EWL) showed biphasic patterns of acclimatory responses. The 2 phases were distinctly differentiated by plateau days. Phase 1 characterized by a sharp decline in ADFI/$BW^{0.75}$ followed by a gradual increase until the plateau, while Tr, RITr and EWL increased sharply followed by gradual decreases until the plateau. Beyond the plateau (phase 2), homeostatic responses in ADFI/$BW^{0.75}$, Tr, RITr and EWL were observed toward the end of the study. Acclimated birds were able to withstand the simulated heat wave with 0% mortality, lower Tr, and longer survival time compared to the control. In conclusion, acclimation could protect birds from acute heat waves and associated heat stress mortality until marketing age. However, applicability of these results towards the industry needs further investigations.

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1. Introduction

Heat stress is one of the main limiting factors of production efficiency in warm regions (Lin et al., 2006). Heat stress-related problems will become more frequent in the future due to global warming (Hansen et al., 2010). When ambient temperature exceeds the comfort level of a bird, feed consumption is reduced to limit the metabolic heat production (Sykes and Fataftah, 1986; Swennen et al., 2007), which adversely affects performance and profitability (St-Pierre et al., 2003; Quinteiro-Filho et al., 2010). Broiler birds are intensively selected for high growth rates which are associated with high metabolic heat production (Havenstein et al., 2003; Gous, 2010). However, genetic improvements of physiological systems that support energy balance and heat tolerance were not included in breeding programs. Chickens thermotolerance can be improved by thermal manipulation during embryogenesis (Tona et al., 2008; Piestun et al., 2013) or thermal conditioning at early ages (Yahav and McMurtry, 2001; Tona et al., 2008). Improving thermotolerance without adversely affecting performance is a target for commercial broiler farming in warm regions. We hypothesized that acclimation by short periods of repeated intermittent heat exposure can improve the acquisition of thermotolerance without adverse effects on performance. According to Sykes and Fataftah (1986), acclimation to heat stress was achieved after 7 d of heat exposure in laying hens, indicating a plateau day where homeostasis has been reached in acclimation. Horowitz (2001) provided evidence for a biphasic pattern of acclimatory responses to cope with heat stress; the short-term heat acclimation (STHA) phase that is characterized by rapid thermoregulatory responses at the expense of homeostasis followed by the long-term heat acclimation (LTHA) phase where long acting protective mechanisms attained their full expression and homeostasis in acclimation is achieved. The threshold days that marked the end of the STHA phase and the beginning of the LTHA phase were recently confirmed in pigs while the responses were affected by the magnitude of heat stress (Renaudeau et al., 2010; Renaudeau et al., 2011). Therefore, the objectives of the present study were to investigate the optimum period of intermittent heat exposure that can induce sufficient physiological acclimation and to investigate the effect of the duration of heat exposure on performance and acclimation pattern in broiler birds. Another objective was to

Abbreviations: ADG, average daily gain; BW, body weight; ADFI/$BW^{0.75}$, average daily feed intake per kg of metabolic BW; Tr, rectal temperature; RITr, rate of increase in rectal temperature; EWL, evaporative water loss

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evaluate the thermotolerance of non-acclimated and acclimated broiler birds under simulated heat wave climatic conditions at marketing age.

2. Materials and method

2.1. Birds management and experimental design

Birds care and handling were in compliance with the regulations of the European Parliament and the European Council Directive on the protection of animals used for scientific purposes (2010/63/EU). This experiment was conducted at the Environment and Animal Physiology Lab, Faculty of Agriculture, The University of Jordan. One-day-old Hubbard broiler chicks were obtained from a commercial hatchery and reared under routine management practice. At 14 d of age, 160 birds (80 male + 80 female) were randomly selected and moved to climate-controlled chambers equipped with metal slatted battery cages. Each bird was tagged, kept in individual cage (dimensions: $37\times30\times40$ cm^3) and provided with feeder and a nipple drinker. Standard grower and finisher rations based on maize and soybean meal were balanced to meet the nutrient requirements for broiler chickens (National Research Council, 1994) and offered ad libitum.

The experiment was divided in 2 periods: pre-acclimation period (P0) and acclimation period (P1). During P0 birds were adapted to experimental conditions (housing, diet, and measurements) for 7 d, while ambient temperature was maintained at 22 ± 1 °C and RH at 62 ± 2%. At 21 d of age (beginning of P1), birds were allocated into 5 treatments (T) of 32 birds per treatment (16 male + 16 female). T1, T2, T3 and T4 were acclimated by daily exposure to heat (38 ± 1 °C, 62 ± 2% RH) for 1, 2, 3 and 4 h/d, respectively, for 14 d. T0 was the non-acclimated control and kept at 22 ± 2 °C and 65 ± 2% RH throughout the experimental period. The thermotolerance of non-acclimated and acclimated birds was evaluated under simulated heat wave conditions at day 36 of age (marketing age) by exposing them to a high ambient temperature (43 ± 1 °C, 55 ± 3% RH) for 4 h. This protocol was applied to simulate the abrupt increase in ambient temperature in natural environment when a sudden heat wave strikes. This high temperature (43 °C $\pm$ 1) was used to minimize the temperature gradient between body and surrounding environment.

2.2. Measurements

Body weight (BW) and average daily feed intake (ADFI) were measured for each bird every morning at 07:00. The daily feed intake per kg of metabolic body weight (ADFI/BW$^{0.75}$) was calculated based on metabolic body weight (BW$^{0.75}$) and expressed as g/d/kg of BW$^{0.75}$. Rectal temperature was calculated for P0 and P1 and expressed as the average of daily measured Tr. Rectal temperature (Tr) was measured before the start of heat exposure at 09:00 for all treatment groups and then at hourly intervals depending on the treatment. For T0, the average Tr was calculated based on rectal temperatures measured from 9:00 to 13:00. For the heat exposed groups (T1 to T4), the average Tr was calculated from rectal temperatures measured during the heat exposure periods between 9:00 and 13:00 depending on the treatment. Rate of increase in rectal temperature (RITr) was determined every day by calculating the difference in Tr before the start of heat exposure and at the end of exposure divided by the time between them in hours. Rectal temperature was measured by a digital thermometer (±0.01 °C accuracy) connected to a very fine probe that was inserted for a distance of 3 cm inside the rectum of each bird. Evaporative water loss (EWL) was measured daily for each bird after the end of exposure as described by Sykes and Fataftah (1986). Parameters measured during the simulated heat wave were Tr, RITr, EWL, mortality and survival time (time until Tr reached 45 °C). Air velocity was not controlled, but daily periodical measurements at different sites around birds indicated that it did not exceed 0.15 m/s.

2.3. Statistical analysis

The SAS system (SAS Institute, 2010, Version 9.1.3) was used to conduct all statistical analysis. The ADG, and ADFI were analyzed with a linear mixed model that included the effects of treatments (duration of heat exposure = 0, 1, 2, 3, 4 h), day of heat exposure ($d=-6, -5,\ldots, 0, 1,\ldots,14$) and their interactions. Tukey test was used to separate means for significant interactions according to the pdiff procedure of the SAS. Data of Tr, RITr, EWL, and ADFI/BW$^{0.75}$ were submitted to a nonlinear segmented regression with plateau analysis to estimate the point at which the plateau begins (the breakpoint). The plateau was defined as a threshold value beyond which desired effects occur (when birds reached a homeostasis in acclimation response). The threshold day was considered as the breakpoint between the different phases of acclimatory responses. The model used was:

$$Y_i=\beta_0+\beta_1 x_i+\varepsilon_i \quad \text{for} \quad x_i\le x_0$$

or

$$Y_i=(\beta_0-\beta_2 x_0)+(\beta_1+\beta_2)x_i+\varepsilon_i \quad \text{for} \quad x_i> x_0$$

where Y = the response variable (Tr, RITr, EWL, and ADFI/BW$^{0.75}$);
x_i = day of heat exposure;
x_0 = the plateau day (breakpoint);
β_0, β_1 and β_2 are the parameter estimators; and
ε_i = random error.

The PARMS statement of SAS was used to define parameters with their priors, which are needed to start the iterative numerical computation. The NLIN procedure of SAS was used for fitting nonlinear regression. Y_i was the dependent and x_i was the independent variable, and β_0, β_1, β_2 and x_0 were the parameters to be estimated.

The different parameters measured during the simulated heat wave test were analyzed with GLM procedure of SAS that included the effects of 5 treatments (duration of heat exposure = 0, 1, 2, 3, and 4 h). Birds' survival time during the simulated heat wave was analyzed as a time-dependent variable because some birds had failed to complete the test. This kind of data can be better described by survival data analysis. Therefore, parameters measured during the thermotolerance test were submitted to Survival Data analysis of SAS procedures using the PROC LIFETEST statement. This procedure offers the advantage of using censored and uncensored records with clear discrimination between birds culled/died early or late in the test. The risk of culling occurrence at any time was estimated by the Hazard Rate that followed the Weibull distribution. The validity of applying the Weibull proportional hazard model was assessed from the plot of the Kaplan–Meier as a nonparametric estimation of the survival curve. Mortality data were positively skewed (Skewness > 0) and showed non-Gaussian distributions (Kolmogorow–Smirnow, $P<0.05$), therefore transformation with a natural logarithm (ln) function [$\ln(y)=\ln(y+10)$] was applied to correct for heterogeneity of variance and produce an approximately normally distributed data set.

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