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Physiological and behavioural parameters of broiler chicks grown under different heating systems

P.F.P. Ferraz[1,*], E.T. Andrade[1], R.B. Vilas Boas[1], T. Yanagi Junior[1], R.R. Andrade[2], V. Becciolini[3] and M. Barbari[3]

[1]Federal University of Lavras, Agricultural Engineering Department, BR37200-000 Lavras, Minas Gerais, Brazil
[2]Federal University of Goiás, Department of Biosystems Engineering, College of Agronomy, BR74690-900 Goiânia, Brazil
[3]University of Florence, Department of Agriculture, Food, Environment and Forestry, Via San Bonaventura 13, IT50145 Firenze, Italy
[*]Correspondence: paricia.ponciano@ufla.br

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Abstract. This study aimed to compare the internal environment, physiological variables, and behavioural responses of chicks under two different heating systems. The experiment was performed in two commercial broiler houses located in Brazil, where 28,000 male Cobb chicks were housed during the first three weeks of life. One of the broiler houses was heated by an industrial indirect-fired biomass furnace (S1). In addition, another heating system consisting of two furnaces for indirect heating of the air using biomass (wood) as fuel, built by hand with bricks, mud, and dung on an iron structure (S2), was tested. Measurements of the dry bulb temperature (t_{db}), dew point temperature (t_{dp}), and relative air humidity (RH) were performed. Subsequently, the temperature-humidity index (THI) was calculated. In addition, the physiological variables of the respiratory rate (RR) and cloacal temperature ($t_{cloacal}$) were measured three times a day (8:00 am, 2:00 pm, and 6:00 pm) in four chicks. The behaviours were grouped by dendrograms, in which the similarity of these data was qualified. During the second and third weeks of life, the THI values were below the recommended range. The RR and $t_{cloacal}$ data were below the recommended comfort values, which may be an indicator that the chicks were subjected to cold conditions. Regarding their behaviour, the chicks exhibited calm, feeding, and sleepy behaviours most of the time. Problems in the heating system inside the broiler house could be observed, possibly affecting the chicks' thermal comfort and welfare, which consequently can result in productive and economic losses.

Key words: chicks, behaviour, cloacal temperature, respiratory rate, thermal comfort.

INTRODUCTION

The production of broiler chickens occupies a prominent position in the Brazilian economy, in addition to providing the consumer with an affordable source of protein. However, the predominant characteristics of the tropical and subtropical climate, as in Brazil, require specific care in relation to the thermal environment control in which the birds are inserted (Oliveira et al., 2018; Cândido et al., 2019; Coelho et al., 2019). The thermal environment conditions to which broilers are subjected are essential to ensure maximum comfort and animal welfare, and consequently, achieve maximum productivity (Vieira et al., 2016). For the Brazilian climatic conditions, there is a need for supplementary heating during the initial phase of the birds' life, as they are sensitive to the cold (Andrade et al., 2019).

In the early stages of chicken growth, birds have low tolerance to thermal stress, which can result in reduced productivity and reproductive performance. A chick is considered a poikilothermic animal, i.e., its body temperature varies according to the ambient temperature (Souza et al., 2015). This is because, in the initial stage of rearing, birds do not have a defined thermoregulatory system or sufficient energy reserves to adapt to adverse environmental conditions, so body temperature can vary depending on the ambient temperature (Ponciano et al., 2012; Andrade et al., 2017). When under cold stress, there is a decrease in growth performance and immune function in broiler chickens (Su et al., 2020). Thus, the first weeks of life of birds are the most critical, and errors made in this phase cannot be corrected, resulting in a decrease in the final performance (Cordeiro et al., 2010).

This highlights the importance of adapting the environment to the ideal welfare conditions for younger birds. However, the quantification of only the thermal environment to which an animal is subjected is not sufficient to meet the real welfare needs of the animal, and the creation environment directly influences its behavioural expression in physiological aspects and productive responses (Ponciano et al., 2011). The physiological responses that may be affected by heat stress include the cloacal temperature ($t_{cloacal}$) and respiratory rate (RR) (Ferreira et al., 2012; Andrade et al., 2018). In this way, great advances, investments and new forms of management have been continuously developed in the poultry sector.

Thus, the objective of the present study was to analyse two broiler houses with different heating systems based on environmental, physiological, and behavioural variables during the first three weeks of life of chicks.

MATERIALS AND METHODS

The experiment was conducted in two commercial broiler houses in the western mesoregion of Minas Gerais, Brazil, during the spring season. The two broiler houses are 13 m in width, 160 m in length, and 3 metres in ceiling height, with a 30° roof slope, 6-mm-thick asbestos cement roofing, a concrete floor, rice husk bedding, side curtains and yellow plastic canvas lining at 2.45 m height. In each broiler house, double curtains were used as side walls (one internal and one external). The internal curtains were removed on the fifth day of life of the chicks, and the external curtains were managed according to the climatic conditions throughout the experimental period.

The one broiler house had the S1 heating system, which consisted of two furnaces with indirect-fired biomass burning, built by hand with bricks, mud, and dung on an iron structure, located 80 m apart. Each furnace was 1.88 m long, 1.27 m wide, and 1.58 m high. The furnace was operated with a three-phase motor with 2,206 W of power at 1,725 RPM; this motor supplied heated air to the broiler house through a 0.10 m diameter tube. In the broiler house with the S2 heating system, the heating system consisted of an industrial metal furnace with indirect-fired biomass burning, with a length of 2.23 m, width of 1.23 m, and height of 1.85 m. The heated air was blown by a three-phase motor with 2,206 W of power at 1,725 RPM through approximately 28.6 m of galvanized steel tubing on the northeast side and 22.45 m on the southwest side installed in the central internal part of the broiler house. The tubing had a diameter of 0.23 m and holes 0.05 m in diameter separated by 1.0 m located alternately on each side to release the heated air.

A total of 28,000 male Cobb chicks aged 1 to 21 days were housed in each broiler house. The diets provided to the animals were formulated according to the nutritional requirements of the different growth stages of the birds, with the same formulations for both systems.

To characterize the thermal environment, daily measurements of the dry bulb temperature (t_{db}, °C), dew point temperature (t_{dp}, °C), and relative humidity (RH, %) were taken at a height of 10.0 cm from the litter, in intervals of five minutes, at 8:00 am, 2:00 pm, and 6:00 pm in the first three weeks of life. T_{db}, t_{dp} and RH were measured using sensors (Hobo Pro Series - Onset®), with precision of ± 3% of the reading.

The thermal environment inside the broiler houses was characterized by the temperature-humidity index (THI). The THI is considered one of the simplest indices and has stood out because it encompasses the effects of t_{dp} and RH. This index can be calculated by Equation 1, developed by Thom (1959).

$$THI = t_{db} + 0.36 \times t_{dp} + 41.5 \qquad (1)$$

where t_{db} = dry bulb temperature (°C); t_{dp} = dew point temperature (°C).

The RR and $t_{cloacal}$ of the chicks were evaluated three times a day (8:00 am, 2:00 pm, and 6:00 pm) in four randomly selected chicks, totalling 12 chick's broiler^{-1} day^{-1}. The $t_{cloacal}$ value was measured using a digital thermometer (precision of ± 0.2 °C). The RR was determined by direct visual observation for 15 s, and then this value was extrapolated to one minute.

The behaviour of the chicks was evaluated by observation with monitoring of the group of animals in continuous time intervals of 10 minutes for each broiler house. Evaluations were performed at 8:00 am, 2:00 pm, and 6:00 pm in the first three weeks of life. The analyses were performed daily for 21 days. The behavioural patterns were adapted from Sevegnani et al. (2005), and include the frequency of calm, scattered, prostrate, gasping, feeding, drinking water, and sleepy behaviours. These behavioural patterns were characterized by scoring as a function of time and number of chicks performing each behaviour, similar to the methodology described by Schiassi et al. (2015). For the statistical analysis of the scores assigned to the behavioural patterns, exploratory analyses using radar charts and agglomerative hierarchical clustering (AHC) were used.

Statistical design

Environmental and physiological variables

For the analysis of environmental and physiological variables, a 2×3×3 factorial design was used, composed of the following factors: broiler house (S1 and S2), week (1, 2, and 3), and period (8:00 am, 2:00 pm, and 6:00 pm), through the statistical software Sisvar 5.3 (Ferreira, 2010). The data were subjected to analysis of variance, and the means of significant interactions were compared using the Skott-Knott test, at the 5% significance level.

Behavioural variables

The behaviours of the chicks were analysed using the AHC methodology, which separates objects into groups based on the characteristics of these objects, through classification criteria, such that there is homogeneity within the group and heterogeneity between groups, allowing grouping of the treatments in which the chicks showed similar behaviours (Ferraz et al., 2014). The results of the AHC method were described using a dendrogram, which is a similarity diagram, quantified using the Ward method and Euclidean distance, as described by Lau et al. (2009). The cophenetic correlation coefficient (CCC) was used to evaluate the consistency of the clustering obtained with the AHC method, with values close to one indicating better representation.

To group the behaviour of the chicks according to their similarity, the data were subjected to multivariate cluster analysis (R Development Core Team, 2020).

RESULTS AND DISCUSSION

In the statistical analysis of the THI using the Scott Knott test, there were no differences between the two broiler houses evaluated ($P = 0.4707$) or the broiler houses x week ($P = 0.7329$). However, there were differences ($p < 0.05$) for the week x period interaction (Table 1).

Although there were no differences between the THI values of the two heating systems evaluated, there were differences between the three weeks of life of the chicks and the three periods analysed (Table 1). Week 1 had higher THI values than the other weeks studied for both broiler houses. According to Abreu & Abreu (2001), the THI values for broiler chickens should be 72.4 to 80.0, 68.4 to 76.0, and 64.8 to 72.0 in the first, second, and third weeks of life, respectively. Thus, in the first week, the THI values were within the comfort range, but in the second and third weeks, the values were below the values recommended by the literature, showing a possible failure in the heating system in these weeks. According to Schiassi et al. (2015) and Andrade et al. (2018), an inadequate thermal environment can modify the physiological response of chicks, resulting in lower productive performance.

Table 1. Mean THI (temperature-humidity index) values of both broiler houses for the three periods of the day studied (8:00 am, 2:00 pm, and 6:00 pm) throughout the first three weeks of life of the chicks

Week	Period	THI
	1 (8:00 am)	78.80 a
1st	2 (2:00 pm)	80.58 b
	3 (6:00 pm)	80.08 b
	1 (8:00 am)	64.16 b
2nd	2 (2:00 pm)	51.48 a
	3 (6:00 pm)	52.96 a
	1 (8:00 am)	66.27 c
3rd	2 (2:00 pm)	52.22 a
	3 (6:00 pm)	57.88 b

Means followed by different lowercase letters in the column differ by the Scott Knott test ($p < 0.05$).

Table 1 also shows a comparison between the THI values over the three periods of the days analysed (8:00 am, 2:00 pm, and 6:00 pm) throughout the three weeks of bird life. The data indicate variation in the environmental conditions that the chicks were subjected to throughout the days. According to Ferraz et al. (2020), it is expected that in a commercial production system, the environmental variables within the facility are homogeneous. These environmental variations within the broiler house may result in thermal conditions outside the recommended comfort range, which may cause unevenness in the lot, in addition to causing discomfort in the animals and productive and economic losses (Ferraz, et al., 2019).

Table 2 shows the values of the physiological variables, RR and $t_{cloacal}$, of the birds monitored during the experimental period. For these variables, there were no differences between the heating systems evaluated ($p > 0.05$). However, there were differences in all physiological variables between the weeks evaluated.

Table 2 shows that the mean values of the physiological variables RR and $t_{cloacal}$ were higher in the second (68.5 breaths min^{-1} and 41.0 °C, respectively) and third (67.7 breaths min^{-1} and 41.0 °C, respectively) weeks of life of the chicks. As shown in Table 1, in the second and third weeks of life of the chicks, the internal environment of the broiler houses showed THI conditions below the comfort range. According to Cordeiro et al. (2014), chicks in thermal comfort exhibit an RR of approximately 47 breaths. min^{-1}. For the three weeks evaluated in the present study, the RR was above the recommended level. These high RR values may be an indication that the birds were in thermal discomfort during the evaluated period, which generated changes in RR.

Table 2. Mean values of the physiological variables RR and $t_{cloacal}$ in the first, second, and third weeks of life in the both broiler houses

Week	RR (breaths min-^{1})	$t_{cloacal}$ (°C)
1	56.1 a	40.0 a
2	68.5 b	41.0 b
3	67.7 b	41.4 c

Means followed by different letters differ by the Scott Knott test ($p < 0.05$).

The $t_{cloacal}$ values obtained during the first three weeks of the birds' lives showed a significant difference ($p < 0.05$) (Table 2). The values obtained for $t_{cloacal}$ (40.0 °C in the first week, 41.0 °C in the second week and 41.4 °C in the third week), are below the value of 42 °C considered as comfort for the first three weeks of life for broilers, as indicated by Oliveira et al. (2006), being indicative of cold stress.

According to Table 3, for the three evaluated periods (8:00 am, 2:00 pm, and 6:00 pm), the physiological variable RR of the evaluated periods differed significantly ($p < 0.05$). The lowest RR values were observed at 8:00 am, with values of 62.3 breaths min^{-1}, and the highest were observed at 2:00 pm, with a mean of 65.4 breaths min^{-1}, indicating a situation of discomfort for the animals.

Regarding $t_{cloacal}$, there were differences ($p < 0.05$) between the periods studied. In the morning, the chicks had lower $t_{cloacal}$ values than in the afternoon and evening. However, in all periods, the $t_{cloacal}$ remained below the comfort range (42 °C) (Oliveira et al., 2006).

Table 3. Mean values and standard deviation from the multiple comparison test of the RR and $t_{cloacal}$ variables for the period factor, values obtained from the averages of both broiler houses

Period	RR (breaths min^{-1})	$t_{cloacal}$ (°C)
8:00 am	62.3 a	40.7 a
2:00 pm	65.4 c	40.9 b
6:00 pm	64.0 b	40.8 b

Means with different letters (for the column) indicate significant differences ($p < 0.05$), by the Scott Knott test.

Fig. 1 shows the exploratory analysis, in a radar chart, of the frequency of occurrence of each behaviour evaluated in each of the weeks. The behavioural evaluation serves as an indicator of the comfort or discomfort of production animals. This factor should be assessed in the early days to prevent negative effects on animal welfare and productivity. In this sense, the behaviours of the animals are monitored to find ways to improve their welfare (Garcia et al., 2015), providing a new perspective for the conventional animal production model and generating alternatives to conditions not previously considered or poorly understood in animal welfare (Pinheiro et al., 2015). This is a non-invasive procedure in which the animals themselves are the biosensors that respond to environmental variations.

As shown in Fig. 1, throughout the 3 weeks of life, the chicks showed behaviour indicative of comfort even though the THI values were below the thermal comfort range. It can be observed that the chicks spent most of the time exhibiting calm behaviour (22.6, 20.5, and 21.8% of the time for the first, second, and third week, respectively), sleepy behaviour (20.3, 18.6, and 14.3% of the time for the first, second, and third weeks, respectively), and feeding behaviour (16.0, 17.6, and 19.0% of the time for the first, second, and third weeks, respectively). Gasping behaviour was the least observed throughout the observed period (4.2, 5.5, and 4.6% of the time for the first, second, and third weeks, respectively).

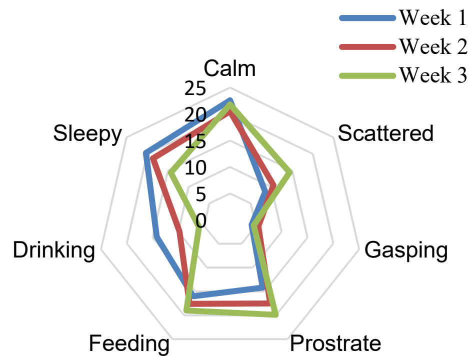

Figure 1. Analysis of the behaviour of the broiler chicks for each experimental week.

Fig. 2 shows a cluster analysis in which the behavioural patterns were grouped and the periods (8 am, 2 pm, and 6 pm) were compared and analysed according to the Euclidean distance scale. For the first week of life (Fig. 2, a), during which the THI was highest (Table 1), the behaviour of the chick's showed characteristics of discomfort due to cold, in which the morning period differed from the other evaluated periods in the distance scale. There were no differences in the distance scale between the afternoon and evening periods.

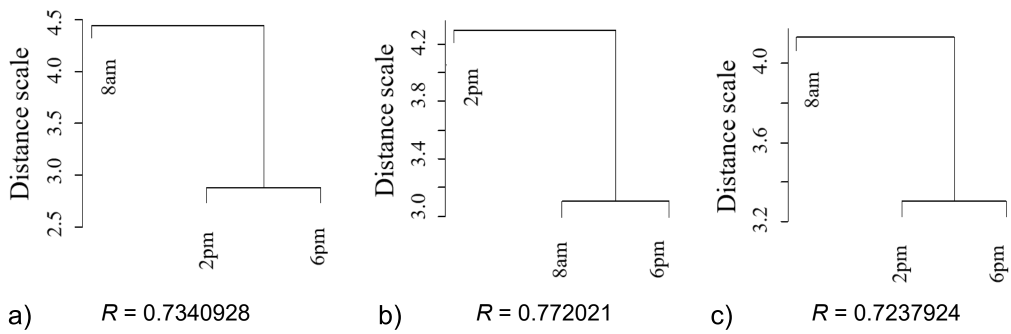

Figure 2. Cluster analysis of the behavioural variables analysed for the morning, afternoon, and evening periods in a) first week of life, b) second week of life, and c) third week of life.

For the second week of life, the THI was below the thermal comfort range (Table 1), especially at 2:00 pm, when the THI was the lowest. This was evidenced in the behaviour analysis of the chicks, where the behaviour at 2:00 pm was different from that at the other times evaluated (Fig. 2, b).

In the third week of life, the behaviour was like that in the first week (Fig. 2, c), and the time of 8:00 am differed from the other two times studied. The chicks were subjected to thermal conditions below comfort (Table 1), and at 8:00 am, the THI values were higher than those at the other times. This was evidenced in the behaviour pattern of the chicks, which at 8:00 am differed from the behaviour patterns at 2:00 pm and 6:00 pm (Fig. 2, c). According to Schiassi et al. (2015), although broilers have the ability to adapt their behaviour to variations in their thermal environment, it is not recommended for there to be a large variation in the thermal conditions of the internal environment in commercial broiler houses. The large temperature variations in the environment can influence the zootechnical responses of the animals, such as feed intake, weight gain and feed conversion, which can lead to production losses not observed only by the behaviour analysis.

The CCC for all grouped behaviours was greater than 0.70. According to Ferraz et al. (2014) and Castro et al. (2017), the values found indicate agreement between the original dissimilarity values and those represented in the dendrogram.

CONCLUSIONS

Based on the results presented, the heating system evaluated had no influence on the values of the measured environmental and physiological parameters, during the trial period. However, differences in the values of these parameters were observed between the analysed periods of the day (8:00 am, 2:00 pm, and 6:00 pm).

Regarding the environmental variables, it can be concluded that only in the first week of life did the THI values show values within the comfort range considered ideal. The THI was below the comfort range in the second and third weeks, which may be indicative of failure in the heating systems of both broiler houses. The cloacal analysis and RR indicated a level outside the comfort range.

Regarding the behaviour during all weeks, the chicks showed calm, feeding, and sleepy behaviours most of the time.

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REFERENCES

Abreu, V.M.N. & Abreu, P.G. 2011. The challenges of the environment on broiler systems in Brazil. *Revista Brasileira de Zootecnia* **40**(special supplement), 1–14. *https://www.alice.cnptia.embrapa.br/bitstream/doc/901939/1/osdesafiosdaambienciasobreossistemas.pdf*. Accessed 24.01.2019. (in Portuguese).

Andrade, R.R., Tinôco, I.D.F., Baêta, F.C., Albino, L.F. & Cecon, P.R. 2019. Influence of different thermal environments on the performance of laying hens during the initial stage of rearing. *Engenharia Agrícola* **39**(1), 32–40. doi: 10.1590/1809-4430-Eng.Agric.v39n1p32-40/2019

Andrade, R.R., Tinôco, I.F.F., Baêta, F.C., Barbari, M., Conti, L., Cecon, P.R., Candido, M.G.L., Martins, I.T.A. & Telles Junior, C.T. 2017. Evaluation of the surface temperature of laying hens in different thermal environments during the initial stage of age based on thermographic images. *Agronomy Research* **15**(3), 629–638.

Andrade, R.R., Tinoco, I.F.F., Souza, C.F., Oliveira, K.P., Barbari, M., Cruz, V.M.F., Baptista, F.J.F., Vilela, M.O., Conti, L. & Rossi, G. 2018. Effect of thermal environment on body temperature of early-stage laying hens. *Agronomy Research* **16**(2), 320–327. doi: 10.15159/AR.18.068

Cândido, M.G.L., Tinôco, I.F.F., Barbari, M., Freitas, L.C.S.R., Dos Santos, T.C., Andrade, R.R., Gates, R.S., Conti, L. & Rossi, G. 2019. Effect of environmental temperature during the of brooding period on growing period of pullets viscera and tibia. *Agronomy Research* **17**(2), 371–377. doi: 10.15159/AR.19.106

Castro, J.O., Junior, T.Y., Ferraz, P.F.P. & Fassani, É.J. 2017. Behavior of Japanese quails subjected to different temperatures. *Energia na Agricultura* **32**(2), 141–147 (in Portuguese). doi: 10.17224/EnergAgric.2017v32n2p141-147

Coelho, D.J.D.R., Tinôco, I.F., Souza, C.F., Baptista, F.J., Barbari, M. & Oliveira, K.P. 2019. Thermal environment of masonry-walled poultry house in the initial life stage of broilers. *Revista Brasileira de Engenharia Agrícola e Ambiental* **23**(3), 203–208.

Cordeiro, M.B., Freitas, H.D., Aquino, E.O. & Sousa, E.M. 2014. Evaluation of thermal stress in free-range chickens reared in climatic conditions in the State of Acre. *Enciclopédia Biosfera* **10**(19), 358–365. (in Portuguese).

Cordeiro, M.B., Tinôco, I.D.F.F., Silva, J.N.D., Vigoderis, R.B., Pinto, F.D.A.D.C. & Cecon, P.R. 2010. Thermal comfort and performance of broiler chicks subjected to different heating systems in the winter period. *Revista Brasileira de Zootecnia* **39**(1), 217–224 (in Portuguese).

Ferraz, P.F.P., Gonzalez, V.C., Ferraz, G.A.S., Damasceno, F.A., Osorio, J.A.S. & Conti, L. 2020. Assessment of spatial variability of environmental variables of a typical house of laying hens in Colombia: Antioquia state Case. *Agronomy Research* **18**(S2), 1244–1254.

Ferraz, P.F.P., Ferraz, G.A.S., Schiassi, L., Nogueira, V.H.B., Barbari, M. & Damasceno, F.A. 2019. Spatial variability of litter temperature, relative air humidity and skin temperature of chicks in a commercial broiler house. *Agronomy Research* **17**(2), 408–417. doi: 10.15159/ar.19.112.

Ferraz, P.F.P, Yanagi Junior, T., Alvarenga, T.A., Reis, G.M. & Campos, A.T. 2014. Behavior of chicks subjected to thermal challenge. *Engenharia Agrícola* **34**(6), 1039–1049. doi: 10.1590/S0100-69162014000600002

Ferreira, L., Yanagi Junior, T., Lacerda, W.S. & Rabelo, G.F. 2012. A fuzzy system for cloacal temperature prediction of broiler chickens. *Ciência Rural* **42**(1), 166–171. doi: 10.1590/S0103-84782012000100027

Ferreira, D.F. 2010. Statistical Analysis Software (Statistical Analysis Software) and Experiment planning -SISVAR 5.3. Federal University of Lavras.

Garcia, E.R. de M, Nunes, K.C., da Cruz, F.K., Ferraz, A.L.J., Batista, N.R. & Barbosa Filho, J.A. 2015. Behaviour of laying hens raised in different population densities of housing. *Arquivos de Ciências Veterinárias e Zoologia da UNIPAR* **18**(2), 87–93 (in Portuguese).

Lau, J., Hung, W.T. & Cheung, C.S. 2009. Interpretation of air quality in relation to monitoring station's surroundings. *Atmospheric Environmetric* **43**(4), 769–777. doi: 10.1016/j.atmosenv.2008.11.008

Oliveira, K.P., Ferreira, C.F.S., Tinoco, I.F.F., Andrade, R.R., Barbari, M., Cruz, V.M.F., Baptista, F.J.F., Vieira, M.F.A. Conti, L. & Rossi, G. 2018. Productive performance of broilers at the final stage of breeding submitted to different levels of metabolizable energy in different thermal environments. *Agronomy Research* **16**(2), 556563. doi: 10.15159/AR.18.069

Oliveira, R.F.M.D., Donzele, J.L., Abreu, M.L.T.D., Ferreira, R.A., Vaz, R.G.M.V. & Cella, P.S. 2006. Effects of temperature and relative humidity on the performance and yield of prime cuts of broilers from 1 to 49 days of age. *Revista Brasileira de Zootecnia* **35**(3), 797–803. (in Portuguese). doi: 10.1590/S1516-35982006000300023

Pinheiro, R., Jorge, A., Miranda-De La Lama, G., Souza, H. & Pinheiro, R. 2015. Pre-slaughter management of ewes for disposal: loss of body weight, meat quality and animal behaviour. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia* **67**(1), 227–234 (in Portuguese).

Ponciano, P.F., Lopes, M.A., Junior, T.Y. & Ferraz, G.A.S. 2011. Analysis of the environment for chickens using fuzzy logic: a review. *Archivos de Zootecnia* **60**(232), 1–13.

Ponciano, P.F., Yanagi Junior, T., Schiassi, L., Campos, A. T. & Nascimento, J.W.B. 2012. Sistema fuzzy para predição do desempenho produtivo de frangos de corte de 1 a 21 dias de idade. *Engenharia Agrícola* **32**, 446–458. doi: 10.1590/S0100-69162012000300004

R Development Core Team. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2020.

Sevegnani, K.B., Caror, I.W., Pandorfi, H., da Silva, I.J. & Moura, D.J.D. 2005. Precision animal science: image analysis in the study of broiler behavior under heat stress. *Revista Brasileira de Engenharia Agrícola e Ambiental* **9**(1), 115–119. doi: 10.1590/S1415-43662005000100017

Souza, B.B., Silva, R.C., Rodrigues, L.R., Rodrigues, V.P. & de Souza Arruda, A. 2015. Analysis of the effect of heat stress on poultry production, physiology and diet. *Agropecuária científica no semiárido* **11**(2), 22–26.

Schiassi, L., Yanagi Junior, T., Ferraz, P.F., Campos, A.T., Silva, G.R. & Abreu, L.H. 2015. Behaviour of broilers subjected to different thermal environments. *Engenharia Agrícola* **35**(3), 390–396 (in Portuguese). doi: 10.1590/1809-4430-Eng.Agric.v35n3p390-396/2015

Su, Y., Li, S., Xin, H., Li, J., Li, X., Zhang, R., Li, J. & Bao, J. 2020. Proper cold stimulation starting at an earlier age can enhance immunity and improve adaptability to cold stress in broilers. *Poultry science* **99**(1), 129–141. doi: 10.3382/ps/pez570

Thom, E.C. 1958. Cooling Degree: Day Air Conditioning. Heating, and Ventilating. *Transaction of the American Society of Heating* **55**, 65–72.

Vieira, F.M.C., Silva, I.D., Nazareno, A.C., Faria, P.N. & Miranda, K.O.S. 2016. Thermoregulation of day-old chicks subjected to simulated thermal transport environment. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia* **68**(1), 208–214 (in Portuguese). doi:10.1590/1678-4162-7871