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Spatial variability of litter temperature, relative air humidity and skin temperature of chicks in a commercial broiler house

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Abstract. The thermal environment inside a broiler house has a great influence on animal welfare and productivity during the production phase. Among the importance of the chicken litter is the function of absorbing moisture, provide thermal insulation and provide a soft surface for broilers. The skin temperature is an important physiological parameter to quantify the thermal comfort of animals, its variations may occur as a function of thermal variables. So, the aim of this work was to analyse the magnitude and spatial variability of chicken litter temperature and relative humidity of the air and to correlate them with the spatial distribution of chicks' skin surface temperature throughout the broiler house during the 7th, 14th and 21st days of the chicks' life, using geostatistical techniques. The experiment was performed in a commercial broiler house located in the western mesoregion of Minas Gerais, Brazil, where 28,000 male Cobb chicks were housed. The heating system consisted of an industrial indirect-fired biomass furnace. The heated air was inflated by an AC motor, 2,206 W of power, 1,725 RPM. Geostatistical techniques were used through semivariogram analysis and isochore maps were generated through data interpolation by kriging. The semivariogram was fitted by the restricted maximum likelihood method. The used mathematical model was the spherical one. After fitting the semivariograms, the data were interpolated by ordinary kriging. The semivariograms along with the isochore maps allowed identifying the non-uniformity of spatial distribution of the broiler litter temperature throughout the broiler house for 3 days of chicks' life. It was observed that skin surface presented a positive correlation with the litter temperature and a negative correlation with the air humidity. The semivariograms along with the isochore maps allowed identifying the non-uniformity of spatial [illegible] throughout the broiler aviary for the three days. In addition, the use of geostatistics and distribution maps made possible to identify different environmental conditions in regions inside the broiler house that may harm the development of chicks.

Key words: environment, geostatistics, thermal comfort, physiological responses.

INTRODUCTION

Broiler facilities should provide thermal comfort conditions that ensure animal welfare and enable animals to maximise their genetic potential for production with the least possible energy expenditure (Nascimento et al., 2014).

Environmental factors, such as air temperature and relative humidity, are crucial for animal husbandry because they affect the broiler's most important vital function – homeothermy (Amaral et al., 2011). According to Ferraz et al. (2018), animals housed at adequate air temperatures avoid wasting the metabolic energy contained in the feed because they expend almost no energy maintaining their body temperatures. Therefore, the housing system climate must be controlled so that broiler maintain their normal physiological functions and achieve satisfactory production.

Usually in a facility for broiler commercial production, the animals are commonly raised in open-plan facilities with a litter covered floor (Dunlop et al., 2015). Shepherd & Fairchild, (2010) and Collett (2012) describe litter as a mixture of bedding materials and manure that is used to provide a cushioning and insulating barrier between the broiler and the ground. Some researches in the literature have shown a very complex nature of the heat exchange between air, broiler body and the litter (Bieda & Kobia, 1999, Nawalany et al., 2010, Said et al., 2016). The welfare, health and productivity of broiler chickens can only be achieved by ensuring optimum thermal conditions in the living area of the chicks. Nawalany et al. (2010) affirm that thermal conditions in the living area of chickens are significantly affected not only by air temperature but also by bedding temperature.

The optimal range of relative humidity for chicken during and after brooding is 60–80 and 50–70%, respectively (Xiong et al., 2017). Higher relative air humidity combined with high temperatures cause the poultry to have greater difficulty releasing internal heat through their airways, thus increasing the animals' physiological responses, including respiratory rate, cloacal temperature (Cassuce et al., 2013) and skin surface temperature (Nascimento et al., 2014).

Abreu et al. (2017) suggest that variations in dry-bulb temperature, relative humidity and lighting are the main causes of changes in the animals' physiological responses. Among the physiological responses used to assess chicks' thermal comfort, skin surface temperature stands out because it can be measured to determine the animal's physical status (Nääs et al., 2014).

Under high ambient temperature conditions, animal body temperatures increase, and metabolic heat must be dissipated to lower the body temperature. Per Whittow (1986), part of the heat is transported through the blood stream via the blood flow to the skin surface or mucosa. Thus, under high temperature conditions, the blood vessels will be at their maximum vasodilatation, and much of the heat inside the body will be transported through the blood stream and tissues. Whittow (1986) further explains that when animals are housed under low temperature conditions, their blood vessels will be at their maximum vasoconstriction, and the heat will be transferred through the tissues.

Nowadays, geostatistical techniques are considered an efficient tool to evaluate the thermal variables inside the animal facilities and it have been used by many researches (Cemek et al., 2016, Ferraz et al., 2016; Curi et al., 2017,). Queiroz et al., 2017 suggest that geostatistical mapping using kriging maps can be a highly important tool for analysing environmental conditions in broiler houses because these maps are easily interpreted.

Thus, this study analysed the magnitude and spatial variability of the litter temperature (t_{litter}) and relative air humidity (RH) and correlated these parameters with the spatial distribution of the broilers' skin surface temperatures (t_{skin}) while in the broiler house at days 7, 14 and 21 of the chicks' lives using geostatistical mapping methods.

MATERIALS AND METHOD

This experiment was conducted in a broiler house on a commercial farm in Minas Gerais, Brazil (20°11'58" latitude South and 45°02'08" longitude West), in the spring. The area's Köppen climate classification is type Cwa, or humid mild climate with dry winters and hot summers (de Sá Junior et al., 2012).

The broiler house in which the experiment was conducted was 13 m wide, 160 m long and 3 m high (Fig. 1) and was oriented northeast-southwest. The broiler house was made of reinforced concrete and bricks, fibre cement roof tiles, concrete flooring, and rice husk litter approximately 10 cm high. The broiler house housed 28,000 Cobb male chicks aged 1 to 21 days.

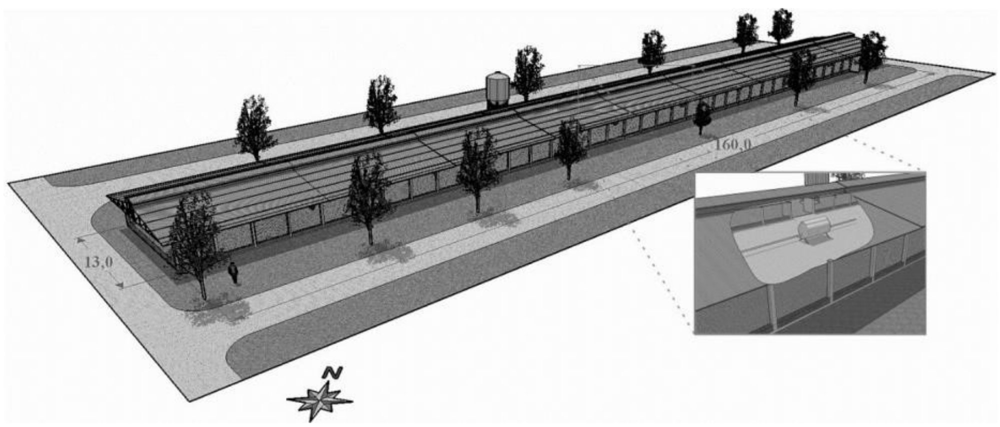

Figure 1. Three-dimensional diagram of the broiler house and heating system evaluated in this study, indicating the main dimensions in metres.

The broiler house's heating system consisted of a 2.23-m-long, 1.23-m-wide and 1.85-m-high metallic industrial indirect biomass fired hot-air furnace. The heated air was blown by a three-phase alternating current (AC) motor, 2,206 W power, and 1,725 RPM, distributed along metal pipes of approximately 28.60 m long on the northeast side and 22.45 m long on the southwest side installed in the central inner portion of the broiler house. The pipes were 23.00 cm wide and had 5.00-cm-wide holes every 1.00 m alternately on each side to release heated air.

Throughout the study period, the litter temperature (t_{litter}), relative air humidity (RH) and the animals' skin surface temperatures (t_{skin}) were measured on days 7, 14 and 21 of the chicks' lives. A digital infrared sensor Raynger ST (Raytek, Berlin, Germany), accurate to 0.5 °C was used to measure the t_{litter} and t_{skin}. The t_{skin} was measured under the wing, using the method proposed by Amaral et al. (2011). The RH was measured using a humidity probe, with a ± 3.00% reading accuracy. The sensors used to measure the t_{litter}, t_{skin} and RH were placed forming a 1.00 × 1.00 m grid, totalling 75 collection points per variable on each day of analysis.

The variables' spatial variations during the experimental period were analysed by semivariogram fitting and ordinary kriging interpolation. The classic semivariogram was estimated using Eq. 1:

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \quad (1)$$

where N (h) is the number of experimental observation pairs, Z(xi) and Z (xi + h), separated by a distance, h.

The semivariogram was fitted using the restricted maximum likelihood (REML) method, which results in less biased estimates. The mathematical model used to fit the semivariogram was the spherical model, which is widely used in geostatistical studies. The data were interpolated by ordinary kriging. The free software environment for statistical computing and graphics, R (R Development Core Team, 2018), was used for geostatistical analysis and map plotting.

Multivariate principal component analysis was used to plot the surface temperature variations with environmental variables in the broiler house. The free software environment for statistical computing and graphics, R (R Development Core Team, 2018), was used for this purpose.

RESULTS AND DISCUSSION

Fig. 2 shows the air temperature results for the collection period. Maximum values near 35 °C were observed in the first week because a firewood furnace was used to heat the facility.

Macari et al. (2004), Ferreira (2005) and Medeiros et al. (2005) found that thermal comfort conditions for broilers range from 32 to 34 °C in the first week, 28 to 32 °C in the second week and 26 to 28 °C in the third week of age. This explains the decrease in the maximum values for each week of observation as shown in the figure below.

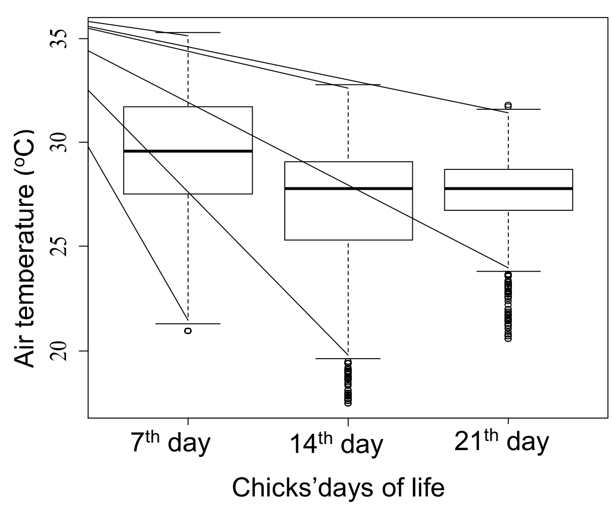

Figure 2. Air temperature distribution on days 7, 14 and 21 of the chicks' lives.

Principal component analysis was used to associate the t_{skin}, t_{litter}, and RH data. Fig. 3 shows that the chicks' skin surface temperatures were strongly positively correlated with the t_{litter} and negatively correlated with the RH. Thus, the data suggest that an increase in t_{litter} as a function of an increase in air temperature will increase the chicks' t_{skin}. Conversely, an increase in RH will decrease the chicks' t_{skin}.

The findings of this study indicate a positive association between t_{skin} and t_{litter} and corroborate the study published by Nascimento et al. (2014), who confirmed the importance of using building materials with low thermal conductivity to help maintain thermal insulation from external temperatures and decrease heat transfer from the facilities to the animals.

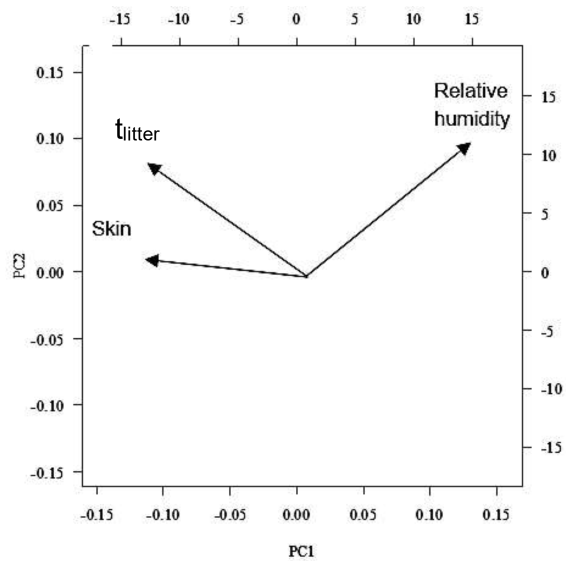

Figure 3. Principal component analysis of the chicks' skin surface temperature (t_{skin}), litter surface temperature (t_{litter}) and relative humidity (RH).

Table 1 lists the estimated experimental semivariograms for the t_{litter}, t_{skin} and RH inside the broiler house on days 1, 7 and 14 of the chicks' lives.

The data varied because the environmental conditions inside the broiler house lacked homogeneity during the experimental period. The nugget effect (C0) is a parameter that indicates unexplainable variability, which can be expressed as the sill ratio, which allows for comparing the degree of spatial dependence (DSD) of the studied variables (Trangmar et al., 1985).

Table 1. Estimated parameters of the experimental semivariograms for litter temperature, skin surface temperature and relative air humidity on days 7, 14 and 21 of the chicks' lives

Variables	C0	C1	C0 + C1	a	SDD		ME
t_{litter}7	2.07	0.94	3.01	34.92	68.79	Moderate	-0.0008
t_{litter}14	2.01	2.32	4.33	38.53	46.45	Moderate	0.0003
t_{litter}21	2.07	0.24	2.31	40.60	89.48	Weak	0.0003
t_{skin}7	0.37	0.13	0.50	33.37	74.00	Moderate	0.0003
t_{skin}14	0.29	0.09	0.37	22.28	76.92	Weak	0.0004
t_{skin}21	0.23	0.03	0.26	4.99	87.66	Weak	3.89E-05
RH7	0.79	16.87	17.66	39.36	4.47	Strong	-0.0002
RH14	0.48	13.43	13.90	43.18	3.46	Strong	-0.0094
RH21	0.15	3.60	3.76	43.41	4.04	Strong	-0.0033

C0: nugget effect; C1: contribution; C0 + C1: sill; a: range; DSD: degree of spatial dependence; ME: mean error.

The range (a) is a relevant parameter of a semivariogram because it is related to the spatial dependence threshold, indicating the threshold at which the variable is spatially correlated among the evaluated points. In the present study, the range of the variable t_{litter} varied from 34.92 m to 40.60 m throughout all days and periods under study.

T_{skin} ranged from 4.99 to 33.37 °C, and the RH ranged from 39.36 to 43.41%.

Per Cambardella et al. (1994), semivariograms can be classified as follows: nugget effect < 25.00% of the sill = strong spatial dependence; nugget effect between 25.00 and 75.00% = moderate spatial dependence; and nugget effect > 75.00% = weak spatial dependence.

All DSD values were strong for the RH, whereas the t_{litter} values were moderate on days 7 and 14. The other DSD values were classified as weak; however, all study variables showed spatial dependence.

Per Faraco et al. (2008), the mean error should be as close as possible to zero, which indicates the semivariogram's goodness of fit. The variables outlined in Table 1 met this criterion.

Subsequently, the t_{litter}, RH and t_{skin} values were estimated based on the semivariogram models' spatial dependence (Faraco et al., 2008; Souza et al., 2010). Therefore, kriging performed well in estimating the non sampled values of this variable considering the best-fitting semivariogram. Thus, spatial distribution maps were constructed for all study variables (Figs 4–6), enabling visualising the data's spatiotemporal variability.

Each spatial distribution map shows the image for each day analysed (7, 14 and 21). Analysis of the maps shows that t_{litter} decreased after day 7 (Fig. 4, a), compared with days 14 (Fig. 4, b) and 21 (Fig. 4, c). According to the researches made by Said et al. (2016) comparing the litter temperature in the 10th and 20th day of chicken's age, it was observed biggest values of litter temperature in the 10th day of life. Probably in both cases this effect is directly related to air temperature control during the first days of the chicks' lives, when the broiler house heating systems were turned on.

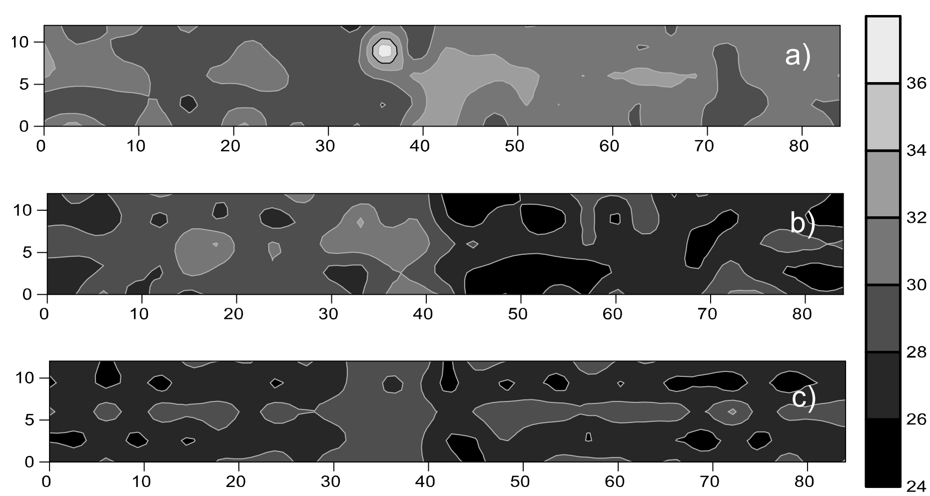

Figure 4. Spatial distribution of the litter temperature for days 7 (a), 14 (b) and 21 (c) of the chicks' lives.

The spatial distribution maps in Fig. 5 show that the heating system with the firewood furnace used in the study facility decreased the RH on days 7 (Fig. 5, a) and 14 (Fig. 5, b) compared with that on day 21 (Fig. 5, c). The increased relative air humidity also led to higher faecal concentrations during the study period because chicks experience increased thermal stress and gain weight as they age; therefore, they drink more water and thus eliminate more water in their excreta, which increases the litter water content (Oliveira et al., 2000). Besides, it can be observed that during all the experimental period the litter humidity exceeded the allowable limit recommended by Butcher & Miles (2014) that is between 25 and 35% relative humidity. According to Said et al. (2016) in case of high humidity it requires regulation of the ventilation system and to monitor constantly the air quality in the broiler house so as not to exceed the levels of harmful substances in the air and minimize of chick's activity.

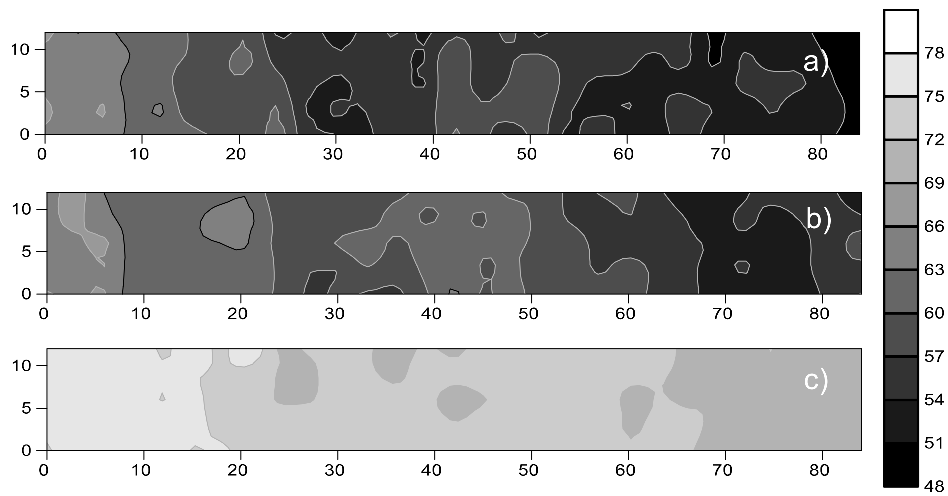

Figure 5. Spatial distribution of the relative humidity on days 7 (a), 14 (b) and 21 (c) of the chicks' lives.

Per Tankson et al. (2001), when broilers are in their thermal comfort zone, their t_{skin} is approximately 33 °C. The results shown in Fig. 6 indicate the effect of the heating system with the firewood furnace used in the study facility on the chicks as they reached maximum t_{skin} values near 40 °C, whereas on subsequent days, the maximum value was 39 °C, and the minimum value was 36 °C.

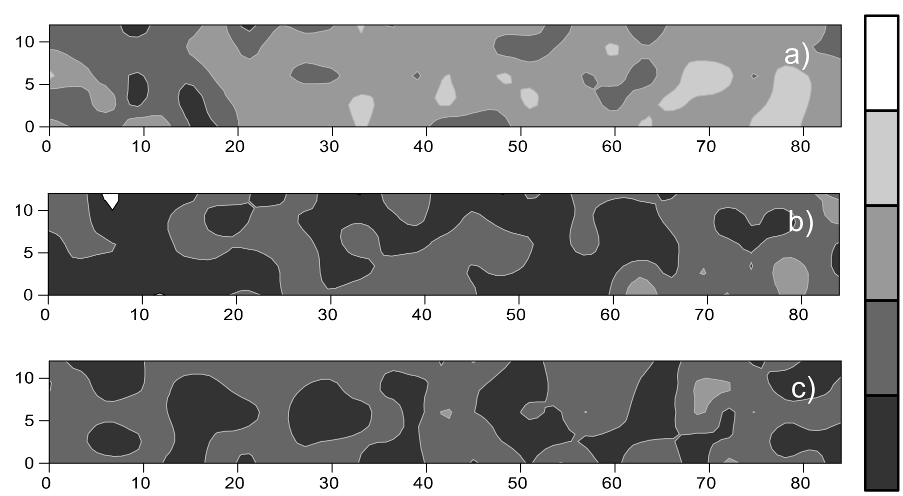

Figure 6. Spatial distribution of the skin temperature on days 7 (a), 14 (b) and 21 (c) of the chicks' lives.

These values highlight the need to control the thermal environment to reduce the chicks' heat stress after their second week of life at the study facility.

A visual analysis of all maps shows how the study data vary in space and the different spatial distribution patterns in each case, which are similar to the findings of Silva et al. (2013) and Curi et al. (2014).

Per Barbosa Filho et al. (2007), broiler tend to exchange body heat via contact with the litter or soil, which is usually at temperatures lower than those of the body, thus favouring heat exchange by thermal conduction. Therefore, the sites where the litter temperature is higher may hinder the chicks' heat exchange by thermal conduction with the litter and favour heat stress conditions, which may negatively affect production.

CONCLUSIONS

The semivariograms and maps enabled efficiently characterising the magnitude and spatial variability of the litter temperature, chick skin temperature and relative air humidity inside the broiler house.

The results showed a positive correlation between litter temperature and the chicks' skin temperature and a negative correlation between relative air humidity and the chicks' skin temperature.

Furthermore, the results showed an uneven spatial distribution of the study variables, which may indicate heating system failures in sections of the broiler house, which may affect the chicks' thermal comfort and welfare.

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