SPATIAL ANALYSIS OF STRESS CONDITIONS INSIDE BROILER HOUSE UNDER TUNNEL VENTILATION

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ABSTRACT: Broiler building typology associated with the local characteristics (climate, topography and surrounding vegetation) and handling systems (stocking density, curtains, equipment and nutrition) influence the inside environment. A spatial distribution analysis of these conditions may indicate stress zones in the house. The aim of this research was to apply spatial analysis of thermal, aerial and acoustic environmental conditions inside a tunnel ventilated broiler housing, with a stocking density of 18 birds m^{-2}. This study was carried out in Rio Claro, SP, Brazil, in a 12 m × 115 m house divided into three equal sections (East, center and West), East-West oriented, and virtually divided on 132 cells, each one measuring 3.0 m × 3.5 m. At the geometric center of each cell the following variables were monitored: dry bulb temperature, relative humidity, air velocity, noise level and light intensity. Average broiler mortality was recorded in each of the three sections. Data collection was made systematically from West to East, opposite to the air flow produced by the tunnel ventilation system, during the warmest period of the day. Measurements took place during the sixth week of production. A geostatistics software tool was used to build spatial distribution maps of the recorded variables in order to infer intermediate stress conditions. It was concluded that the stress zones were located at both ends of the house and the highest mortality index was found at the West sector where the exhaust fans were placed.

Key words: broiler production, environment, geostatistics, heat stress, spatial distribution

ANÁLISE ESPACIAL DE CONDIÇÕES DE ESTRESSE EM GALPÃO DE FRANGO DE CORTE USANDO VENTILAÇÃO TIPO TÚNEL

RESUMO: A tipologia de edificações para abrigo de frangos de corte associada a características do local (clima, topografia e vegetação dos arredores) e os sistemas de manejo (densidade de aves, cortinas, equipamentos e nutrição) influencia as condições internas. A distribuição espacial destas variáveis pode indicar zona de estresse dentro do galpão. O objetivo da pesquisa foi aplicar a análise espacial das condições do ambiente térmico, aéreo e acústico dentro de galpão de produção de frango de corte, usando sistema de ventilação tipo túnel e densidade de 18 aves m-2. O estudo foi conduzido em Rio Claro, SP, em uma edificação com 12 m × 115 m, dividida em três setores (leste, centro e oeste), orientada leste-oeste, contendo virtualmente 132 células, cada uma medindo 3,0 m × 3,5 m. No centro geométrico de cada célula as seguintes variáveis foram medidas instantaneamente: temperatura de bulbo seco, umidade relativa, velocidade do ar, nível de ruído e intensidade de luz. Os dados foram coletados sistematicamente a partir do lado oeste para o lado leste, em direção oposta ao fluxo de ar produzido pela ventilação tipo túnel, no período mais crítico do dia. As medidas foram tomadas quando as aves estavam na sexta semana de produção. A mortalidade média dos frangos foi registrada nos três setores. A ferramenta geostatística foi usada para construir mapas de distribuição espacial das variáveis resultantes de maneira a possibilitar a inferência de posições intermediárias. Concluiu-se que as zonas de estresse estão localizadas nos extremos do galpão e o maior índice de mortalidade foi encontrado no setor oeste, onde estavam os exaustores.

Palavras-chave: produção de frango, ambiente, geostatística, estresse térmico, distribuição espacial

INTRODUCTION

Broiler production under hot weather conditions is well documented (Macari & Gonzales, 1990; Deaton et al., 1997; Aradas et al., 2005), however the interaction between the thermal environment and other factors such as noise level, dust and gases is still not available. The way of providing thermal comfort inside broiler houses under tropical conditions is mainly achieved by the use of forced ventilation associated to fogging (Pereira, 1991; Bottcher et al., 1991; Gates et al., 1991, Czarick & Lacy, 1999) Controlling the physical micro environment in broiler production houses is an important decision to optimize the production process (Bottcher et al., 1991; Gates et al., 1998; Hamrita & Mitchell, 1999), however there is no report in the literature indicating where the critical points or areas (according to the concepts of Hazard Analytical and Critical Control Points, HACCP, 2005) are located inside houses.

The concepts of geostatistics (Krige, 1951; Matheron, 1963) have been applied to several knowledge fieds (Buxton & Pate, 1993; Hunt, 1996; Seixas et al., 1996; Vieira, 2000), and classical statistical analysis has been replaced by the geostatistics approach when the semi-variogram and other methods of interpolating variables are used (Isaaks & Srivastava, 1989). In order to analyze the critical points in the production chain as well as to properly evaluate the welfare status of broilers, geostatistical models can provide accurate maps of variables including production, handling, health status and behavior. Geostatistical models also explore the variability and the continuity of a group of data with spatial regionalization, assuming that spatial uncertainty is controlled by the average statistical properties of the studied environment.

The aim of this research was to generate spatial analysis of aerial, thermal and acoustic variables inside a commercial broiler house using tunnel ventilation to identify critical areas.

MATERIAL AND METHODS

This study was performed during summer, near Rio Claro, SP, Brazil (47°37’52’’ W and 22°24’54” S) with prevailing SE winds, in a East-West oriented commercial broiler house 12 m wide (Y) and 115 m long (X) divided in three sections (East, center and West). Air inlet was at the West side (Figure 1) and the exhausting fans placed on the East side had a maximum flow capacity of 10.5 m^{-3} s^{-1}. Local average daily summer dry bulb temperature was 22.5°C and 80% relative humidity.

The house was divided in 132 equally sized virtual cells, measuring 3.0 m × 3.5 m. At the center of each cell the following variables were monitored: dry bulb temperature, °C (DBT); relative humidity, % (RH); air velocity, m s^{-1} (AV); noise level (NL), dBA; and light intensity (LI), Lux m^{-2}. A portable hydrothermo anemometer (Pacer, USA) was used to collect DBT, RH and AV data while a decibel meter (class II-SVAN 943) was used to record the acoustic pressure level. To measure light intensity a luximeter (Hagner®, USA) was used. Data collection was made systematically from West to East during a hot critical daily period (14:00 to 17:00 h). The recording of the variables took place with the ventilation system in a steady-state condition. The measurements recorded in each cell took approximately 30-40s.

Data recording was made with a population of 22,000 birds at the sixth week of production, when the heat stress and air quality were considered to be a challenge to the birds. Data were measured simultaneously in each cell for 15s after waiting 10s to stabilize bird movements and their respective noise generated by the presence of the data collector. The instruments were arranged in a small box which allowed the displacement of all equipment at the same collecting height (0.25 m above the floor). Accumulated average mortality during the trial was calculated by counting the dead birds in each section (East, center and West) related to the total of birds reared at each specific section.

Geostatistic analysis was used to build the individual spatial distribution maps of the variables, using the concept that the variance between data sampling would enhance their spatial dependence as pointed

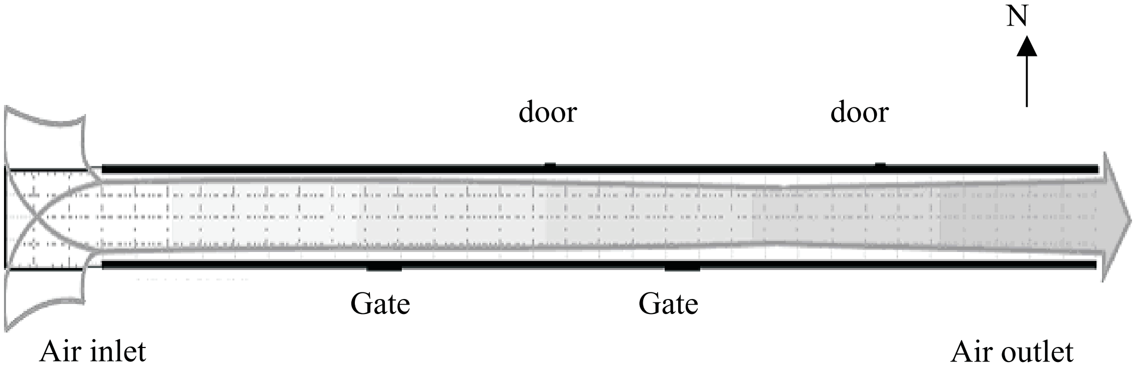

Figure 1 - Schematic drawing of the studied broiler house with the tunnel ventilation system.

out by Matheron (1963). It was assumed that the processes were second order stationary, meaning that the stochastic process can be described by the mean, the variance is constant, and the autocorrelation function exists. The mean (μ) is defined as the expected value of $Z(\vec{x})$:

$$m = E[Z(\vec{x})] \qquad (1)$$

where

$$\hat{m} = \frac{1}{n}\sum_{i=1}^{n} Z(\vec{x}) \qquad (2)$$

The variance of a stochastic process $Z(\vec{x})$ is defined by Equation 3 and estimated by Equation 4:

$$S_Z^2 = E[(Z(\vec{x}) - m)^2] \qquad (3)$$

$$\hat{S}_Z^2 = \frac{1}{n-1}\sum_{i=1}^{n}(Z(\vec{x}) - \overline{Z}(\vec{x}))^2 \qquad (4)$$

where $\overline{Z}(\vec{x})$ is the average form for estimating the variance $Z(\vec{x})$.

The autocovariance for lag h is defined by:

$$g_h = E[(Z(\vec{x}) - m) * (Z(\vec{x} + \vec{h}) - m)] \qquad (5)$$

$$g_0 = S_Z^2$$

assuming that for lag 0 the autocovariance equals the variance. Assuming also that the second order stationary process the variogram is given by Equation 6, and estimated by Equation 7, where N (h) is the number of measured pairs $Z(\vec{x})$ and $Z(\vec{x} + h)$, separated by a vector h.

$$g(h) = 1/2\, E\{Z(\vec{x}) - Z(\vec{x} + h)\}^2 \qquad (6)$$

$$\hat{g}(h) = \frac{1}{2\,N(h)}\sum_{i=1}^{N(h)}[Z(\vec{x}) - Z(\vec{x} + h)]^2 \qquad (7)$$

the graph of $\hat{g}(h)$ as a function of the vector h can be obtained. It depends on the magnitude and direction of h, illustrating the relation between sample variance and lateral distances.

From a theoretical model adjusted to the experimental data, the variogram will provide information to the kriging system, in order to attribute different weights based on modeled range distance of the variogram for spatial interpolation. This system can be written as:

$$\hat{Z}(\vec{x}_0) = \sum_{i=1}^{N} l_i Z(\vec{x}) \qquad (8)$$

where: N is the number of measured values $Z(\vec{x})$ involved with the estimates, and λ_i is the associated weight for each measured value $Z(\vec{x})$ which is a linear estimator, unbiased and with minimum variance (Isaaks & Srivastawa, 1989).

RESULTS AND DISCUSSION

Estimated values of minimum, maximum, mean and variance of each variable (Table 1) show that the light distribution was the most variable as a result of the high intensity of light at the open wall in the West side of the building (air inlet) compared with the rest of the house. On the other hand DBT and AV data presented the lowest variability.

The DBT data distribution was explained based on a Gaussian model among other tested models (Figure 2), where the nugget effect (residual effect) was 0.017, superior limit at 0.22 and range of 31.0 m. This means that up to 0.017 lag the model is only explained by the values of the nugget effect (unexplained variance). Up to the point in the y axis where the curve stabilizes (0.22) the Gaussian model fits and explains the data variation, and the upper limit of the variogram (sill). The range is the limit point where the variables are dependent, and the value of 31 m range reveals that after these distances samples do not have spatial dependence, being independent observations for greater distances.

An estimative map based on DBT ordinary kriging is shown in Figure 3. An area of high temperatures (above 33°C) near both air inlet and outlet is clearly defined. At the air inlet, air temperature was the same as the outside air during data recording (16h00). The map shows that air temperature decreased to approximately 31°C along the building due to the effect of the fogging system. Near to the outlet, air temperature presented a sharp increase along the last 20 m, reaching 34°C. This temperature profile indicates critical points where DBT distribution may represent a challenge for bird occupancy of the floor area. However, this demonstrates also the importance of reducing temperature by using evaporative cooling (Gates et al., 1991).

Table 1 - Data sampling range.

Variable	Minimum	Maximum	Mean	Variance
DBT (°C)	31.5	34.8	32.2	0.33
RH (%)	46.2	63.7	56.2	18.23
A V (m s^{-1})	0.0	2.5	1.4	0.24
Noise (dBA)	59.6	77.3	69.0	11.79
Light (Lux m^{-2})	38.0	4,450.0	308.8	473,230

DBT = Dry Bulb Temperature (°C); RH = Relative Humidity (%); Air Vel = Air Velocity (m s^{-1});
Noise = Noise Level (dBA); Light = Light Intensity (Lux m^{-2}).

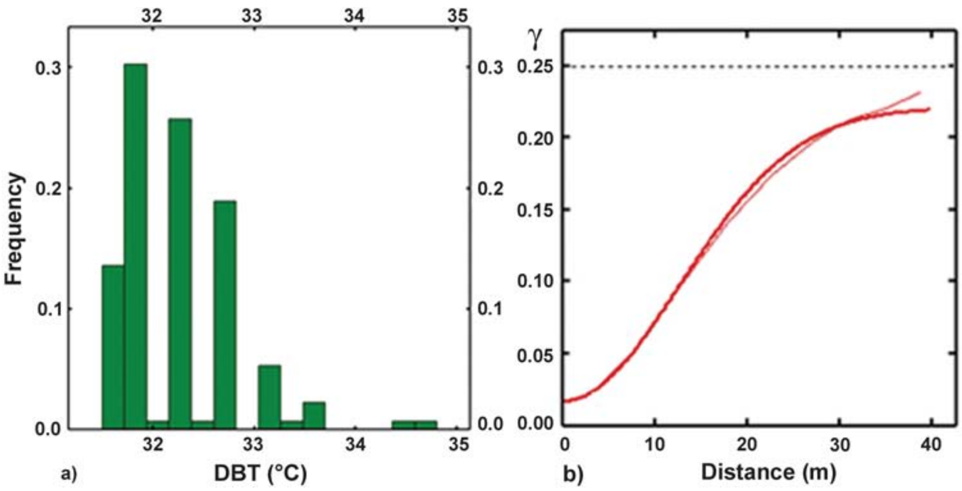

Figure 2 - Histogram (a) and structural analysis (Variogram) (b) of dry bulb temperature inside the broiler house.

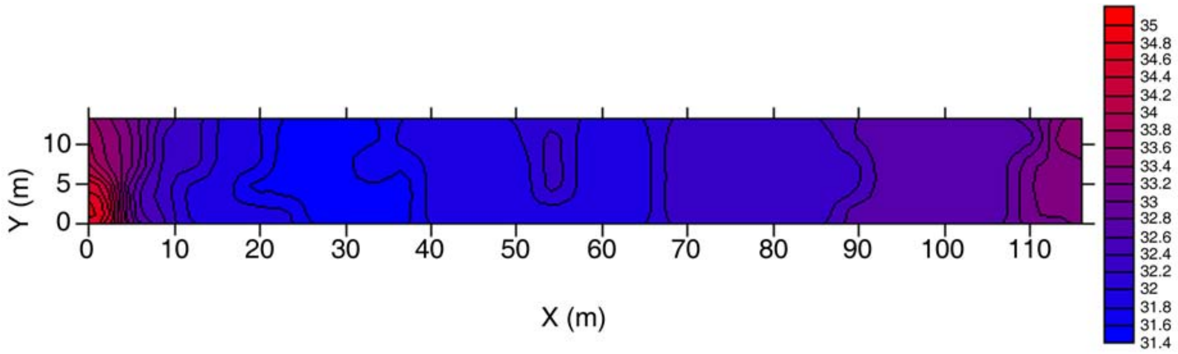

Figure 3 - Dry bulb temperature distribution estimated map (contour interval of 0.2°C).

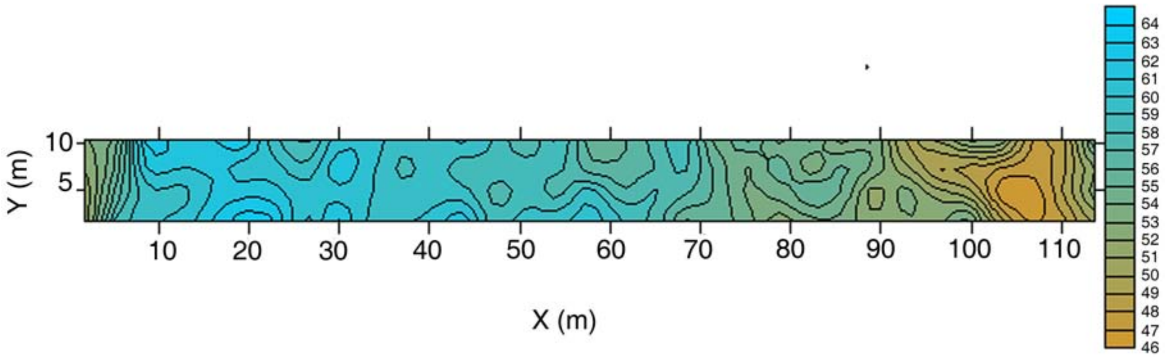

Figure 4 - Relative humidity distribution estimated map (contour interval of 1%) inside the broiler house.

Accumulated mortality (%) was found to be 2.14% in the West sector, 1.61% in the center sector and 0.98% in the East. By overlapping recordings of DBT and accumulated mortality a critical area was found according to the HACCP (2005) concepts, at the West sector close to the air inlet (35°C >DBT>32°C). Macari & Gonzales (1990) and Bottcher & Czarick (1997) attribute high environmental temperature as the main factor influencing both productivity and mortality especially in adult birds.

Relative humidity distribution fitted to an exponential model, and the map can be seen in Figure 4. This model was the best choice between all tested models, with the best fit to the experimental variogram and lowest errors. For this variable the nugget effect (residual effect) was zero, upper limit 6.35 and range of 16.6 m. The estimated map obtained from the geostatistics analysis suggested a distinct pattern of that observed in the DBT map, explained by the psychrometric characteristics of the air.

The exploratory analysis of the air velocity distribution along the building showed that this variable did not present a consistent spatial variability, and its variogram showed a residual effect meaning that the values are independent and randomic. The low value obtained for the variance indicated that the use of tunnel ventilation led to equalization of wind speed inside the housing, as it should if properly designed and operated.

According to Czarick & Lacy (1999) birds exposed to environmental temperatures around 33°C and 1.0 m s^{-1} wind speed tend to feel thermal comfort as if the temperature would be around 26.6°C. However, the house temperatures were still excessive at both ends, and cooling was insufficient to maintain the bird's thermal comfort. Both air inlet and outlet sections can be classified within the stress zone as proposed by Gates et al. (1991) and Deaton et al. (1997).

An exploratory analysis of the noise level (NL) indicated a normal distribution of the values and was fitted by an exponential model with residual effect of 4.54, upper limit 13.54 and range 33.1 m. The estimated map generated by ordinary kriging is presented in Figure 5. Highest values of noise levels were recorded near both ends of the building (greater than 75 dBA) and lower levels in the middle (values lower than 64 dBA). There is an explanation for the high level of noise at the air outlet due to the exhaust fans, however the reason for higher values in the inlet was not identified.

Light intensity exploratory analysis showed a considerable asymmetric distribution of the data as a result of large amount of lower values and some higher values at the air inlet. This distribution presented a log-normal common and rare event; consequently the variance (steady calculated as 473.2 10^3) of this type of data usually presents higher values as observed in this study. Figure 6 shows that data was fitted by a spherical model without nugget effect, upper limit 320.8 10^3 and range 23.0 m. The estimated map obtained by ordinary kriging did not show clearly the variability of these results, nevertheless the differences obtained in this preliminary evaluation reflected the distribution in the building (Figures 7 a, b).

Light intensity results obtained from cells near the curtain along the building presented higher values

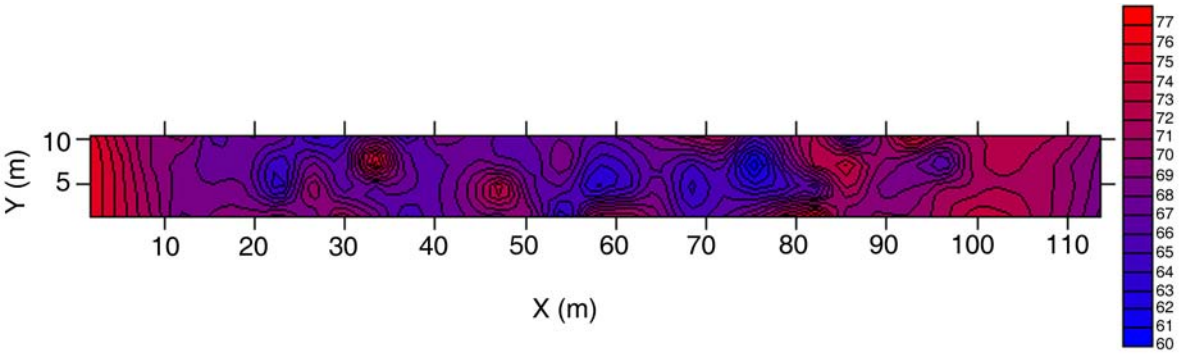

Figure 5 - Noise level distribution estimated map (NL, dBA). Contour interval 1 dBA.

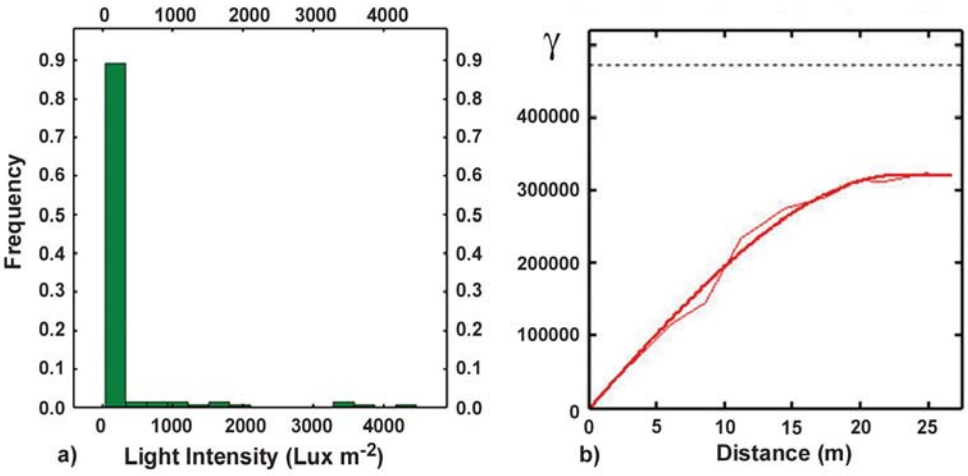

Figure 6 - Histogram (a) and Structural Analyses (Variogram) (b) of Light Intensity data inside the broiler house.

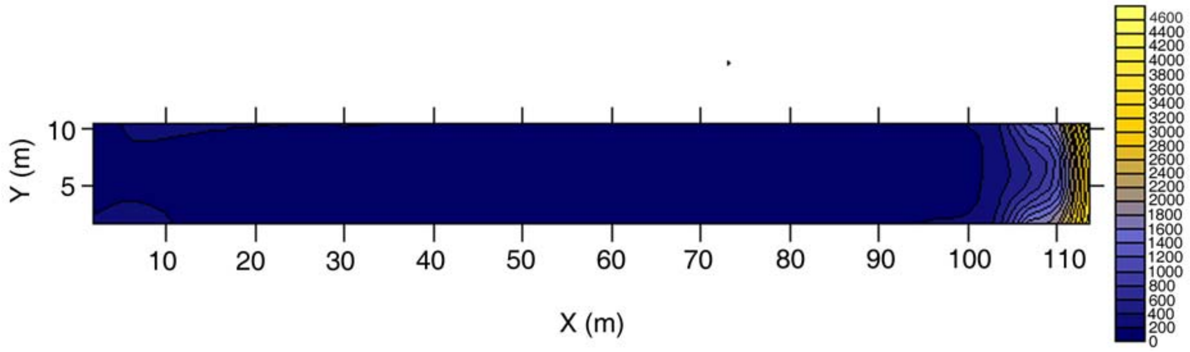

Figure 7 - Light distribution estimated map (contour interval 200 Lux m^{-2}) inside the broiler house.

than cells in the middle. However, this pattern was imperceptible from this first geospatial analysis. The removal of outliers from the West side cells position can be suggested for future evaluations, eliminating extremely high values, in order to determine a more detailed map of the light variation of the tunnel.

Like for DBT, high values of noise level from bird vocalization, and light intensity (LI) from the outside environment were found at both ends of the building. High light exposure inside poultry housing may induce aggressive behavior to the birds at high stocking density (Bottcher & Czarick, 1997), and dark blue curtains are used to reduce sunlight incidence. In this specific study it was not clear if high light exposure induced bird's high vocalization, since birds tend to prostrate under high temperature associated to high solar incidence.

Critical housing conditions of the aerial, thermal and acoustic environment were found in the West sector which also presented higher mortality (2.14%).

In recent years new approaches for food safety and food quality have been developed facing the search for technology in order to meet consumer demand. Today both control and inspection are performed using check-lists, ranking systems, assessment of suppliers, the monitoring of environmental conditions and flock health, to reveal risk elements in each production stage. Using geostatistics concepts of data interpolation the picture of risk points could be determined assuring the mapping of variables associated to production, handling, health and behavior. Furthermore, associating to traceability tools as well as flock identification the results may meet the needs and requirements of future international meat commerce.

CONCLUSIONS

Geostatistics analysis offers a tool for understanding some relations between aerial, thermal and acoustic environmental variables and their spatial variability. Both air inlet and outlet sectors of the analyzed broiler house presented the less favorable environment conditions with high values of dry bulb temperature and light intensity occurring simultaneously with high vocalization of the birds expressed by high noise level. The association of these results to highest mortality in the West sector indicated stressful conditions for reared broilers.

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