Brazilian Journal of Poultry Science
Revista Brasileira de Ciência Avícola

ISSN 1516-635X Oct - Dec 2010 / v.12 / n.4 / 279 - 285

# Characterization of Heat Waves Affecting Mortality Rates of Broilers Between 29 Days and Market Age

**Author(s)**

Vale MM[1]
Moura DJ[2]
Nääs IA[2]
Pereira DF[3]

[1] UFSM / Departamento de Zootecnia. Santa Maria, RS, Brasil.
[2] UNICAMP/FEAGRI. Campinas, SP, Brasil.
[3] UNESP - Universidade Estadual Paulista, Campus de Tupã - SP.

**Mail Address**

MM Vale
Cidade Universitária
Centro de Ciências Rurais - CCR - Prédio 78.
Depto. de Zootecnia, Laboratório de Avicultura - LAVIC.
Avenida Roraima, 1000. Bairro Camobi
97.015-900. Santa Maria, RS, Brasil.

E-mail: mmdovale@hotmail.com

**Keywords**

Heat shock day, heat wave, mortality, productivity losses.

**Acknowledgements**

The authors thank FAPESP, CAPES, and PRODETAB (Banco Mundial/EMBRAPA/FAPESP) for funding this study.

Arrived: July/2010
Approved: September/2010

## ABSTRACT

Climate may affect broiler production, especially where there are heat waves, which may cause high mortality rates due to the heat stress. Heat wave prediction and characterization may allow early mitigation actions to be taken. Data Mining is one of the tools used for such a characterization, particularly when a large number of variables is involved. The objective of this study was to classify heat waves that promote broiler chicken mortality in poultry houses equipped with minimal environmental control. A single day of heat, a heat-shock day, is capable of producing high broiler mortality. In poultry houses equipped with fans and evaporative cooling, the characterization of heat waves affecting broiler mortality between 29 days of age and market age presented 89.34% Model Accuracy and 0.73 Class Precision for high mortality. There was no influence on high mortality (HM) of birds between 29 and 31 days of age. Maximum temperature humidity index (THI) above 30.6 ºC was the main characteristic of days when there was a heat wave, causing high mortality in broilers older than 31 days. The high mortality of broilers between 31 and 40 days of age occurred when maximum THI was above 30.6 ºC and maximum temperature of the day was above 34.4 ºC. There were two main causes of high mortality of broilers older than 40 days: 1) maximum THI above 30.6 ºC and minimum THI equal or lower than 15.5 ºC; 2) maximum THI above 30.6 ºC, minimum THI lower than 15.5 ºC, and the time of maximum temperature later than 15:00h. The heat wave influence on broiler mortality lasted an average of 2.7 days.

## INTRODUCTION

Climatic factors may cause production losses in broiler production. Many of these losses are caused by heat waves, which increase broiler mortality and reduce their productive performance (Johnson, 1997; St-Pierre et al., 2003; Copa/Cogeca, 2004). Moreover, in tropical environments, as that observed in Brazil, that impact might be even worse (Marengo, 2007). The increase in animal production losses predicted by the IPCC (Intergovernmental Panel of Climatic Changes) may reduce the competitiveness of Brazilian meat production, which needs to change its rearing strategies and to train producers to use weather forecast tools (Nääs et al., 2010).

The stress caused by heat affects mainly broilers older than 29 days, which may cause significant mortality rates. Such mortality represents the loss of almost all production resources invested in the process, as birds have almost reached ideal market weight at the time of death (Teeter et al., 1985; Yahav et al., 1995; Tabler et al., 2002; Tao & Xin, 2003; Ryder et al., 2004; Chepete et al., 2005). In addition to higher mortality, live production performance is also reduced, and chicken meat quality is impaired due to higher incidence of PSE meat (pale, soft, and exudative meat) or pale poultry muscle syndrome, which reduces the meat quality (Smith & Northcutt, 2009).

The possibility of predicting climatic events in advance allows to take early mitigation actions that may neutralize or reduce heat wave effects. Different broiler-house environmental control systems show different mitigation and reduction potentials in terms of broiler mortality. However, in some Brazilian regions, most poultry houses have minimal environmental control, and are equipped with forced ventilation, evaporative cooling by fogging, and ceiling insulation with PVC (Tinoco et al., 2004). Using data mining, Vale et al. (2008) studied mortality patterns in poultry houses, and found important patterns associating meteorological data with broiler mortality.

One of the main challenges of heat wave prediction is to define the climatic features that have an impact over the broiler production. Mortality, which is daily recorded in all poultry houses, may be an important parameter to model heat waves. On the other hand, the large number of climatic variables involved may make analyses difficult, and require approaches such as the Data Mining for the classification of days that affect broiler mortality rate.

The objective of this study was to classify heat waves that promote high broiler chicken mortality in poultry houses equipped with minimal environmental control.

## MATERIALS AND METHODS

The experiment was carried out in a poultry farm located in Tuiuti, São Paulo State, Brazil (22°48’056” S; 46°42’046” W, altitude of 807 meters).

The poultry farm has 14 poultry houses, organized in 2 parallel lines, east-west orientation, with dimensions ranging from 72 to 150 m length and 10 m width, built in masonry, covered with clay tiles, and with concrete floors. All poultry houses were equipped with fans, foggers, side curtains, and PVC drop ceiling.

Data on 20 straight-run flocks were collected between October, 2007 and February, 2008, a period when there is usually high incidence of heat waves. Flock placement and exit were determined by the integrator company, which established flock exit according to age. Average bird density used was 13 (±1) birds per meter square. Birds were fed and managed according to the integrator company specification, with no interference of the researchers.

The meteorological data collected were atmospheric pressure, air temperature, air relative humidity, wind speed and direction, and global sun radiation. Data were collected by a meteorological station (Hobo Onset®) placed at the geographical center of the poultry farm. Data were hourly measured and stored in the meteorological station data logger.

Mortality rate of broilers with 29 days of age or older was daily recorded. Mortality rate values above the average and the occurrence of hot day determined mortality classification. High mortality was considered as minimal mortality of 0.2% (twice as high as the mortality in normal days) and was related with the occurrence of minimal climatic conditions for heat wave, which, according to the findings of Vale et al. (2008) includes:

1) maximum temperature equal or higher than 32 ºC;
2) average temperature equal or higher than 24 ºC, and
3) mean temperature and humidity index (THI) equal or higher than 23 ºC. The remaining days were considered as having normal mortality rate.

A new data base was built by associating high or normal mortality classification with the daily average data of the meteorological station, according to the respective days of occurrence.

Data mining techniques were applied to the data according to the CRISP-DM methodology, comprising the following steps: domain understanding, data acquisition, data understanding, data preparation, data modeling and evaluation according to the knowledge from the domain experts (Chapman et al., 2000).

The software used for the analysis was Weka® 3-4 (Witten & Frank, 2005) which consists of a collection of machine-learning algorithms for data mining tasks (e.g., classification). In particular, the classification algorithm chosen was J48, an implementation of the C4.5 (Quinlan, 1993; Quinlan, 1996), which generates a decision tree for classifying broiler mortality as normal or high.

The data base for the analysis included 39 attributes as listed on Table 1.

The model accuracy was calculated by a confusion matrix (Table 2), and it is expressed as the percentage of correctly classified test instances over all test instances, including true-positive and true-negative cases. On the other hand, class precision was also calculated by the confusion matrix (Table 2), and it is expressed as a rate raging from 0 to 1, representing the instances that were correctly classified as true positives in each class (Gomes, 2002).

**Table 1** - Summary of used data and features assumed for organizing the final data set.

| Nº | Feature[1] | Nº | Feature[1] |
|---|---|---|---|
| 1 | ID | 21 | Time to DPT Max |
| 2 | Date | 22 | RH M |
| 3 | Absolute Mortality | 23 | RM Min |
| 4 | Mortality % | 24 | RH Max |
| 5 | Strain | 24 | Time to RH Min |
| 6 | Age (days) | 26 | Time to RH Max |
| 7 | Pa M | 27 | WS M |
| 8 | Pa Min | 28 | WS Min |
| 9 | Pa Max | 29 | WS Max |
| 10 | Time to Pa Max | 30 | Time to WS Min |
| 11 | Time to Pa Min | 31 | Time to WS Max |
| 12 | T M | 32 | WBT M |
| 13 | T Min | 33 | WBT Min |
| 14 | T Max | 34 | WBT Max |
| 15 | Time to T Min | 35 | THI M |
| 16 | Time to T Max | 36 | THI Min |
| 17 | DPT M | 37 | THI Max |
| 18 | DPT Min | 38 | Heat Wave occurrence |
| 19 | DPT Max | 39 | Class HM or NM |
| 20 | Time to DPT Min | | |

1 - Abbreviation list: ID, poultry house identification; Pa, atmospheric pressure; DPT, dew point temperature; RH, relative humidity; WS, wind speed; WBT, wet bulb temperature; THI, Temperature and Humidity Index (Chepete et al., 2005); HM: high broiler mortality; NM: normal broiler mortality; M, mean; Min, minimum; Max, maximum.

**Table 2** - Confusion matrix.

| Class | Predict as C+ | Predict as C- | Class precision | Model Accuracy[1] |
|---|---|---|---|---|
| C+ | True positives (Tp) | False negatives (Fn) | Tp/(Tp+Fn) | [(Tp+Tn)/N]x100 |
| C- | False positives (Fp) | True negatives (Tn) | Tn/(Fp+Tn) | |

1 - N is equal to the number of instances in the test set.

## RESULTS AND DISCUSSION

During the studied period six heat waves were observed, as described in Table 3. Heat waves had a duration between one to five continuous days and mean duration was 2.7 days.

High mortality occurred with one day of heat duration (Table 3), in contradiction to the heat wave definition as presented by the INMET (Brazilian National Meteorological Institute, 2010), Nienaber & Hahn (2004) and Robinson (2001).

**Table 3** - Heat wave incidence.

| Heat wave n. | Broiler age (days) | Duration (days) |
|---|---|---|
| 1 | 30 to 33 | 3 |
| 2 | 45 to 47 | 2 |
| 3 | 29 to 32 | 4 |
| 4 | 33 to 34 | 1 |
| 5 | 38 to 47 | 3 |
| 6 | 43 to 50 | 5 |

Broiler producers and integration service people reported the occurrence of high mortality in a single day of extreme heat. This pattern was also reported by Vale et al. (2008) when studying heat wave impact on broiler production. Heat waves do not have a specific definition, and present different patterns and places of occurrence, and therefore need to be better defined (Robinson, 2001; Abaurrea et al., 2006). According to results presented here, broilers can experience extreme heat exposure in two ways:

1) days with extremely high temperatures or a single day with extreme heat; and
2) heat waves similar to those that impact humans and other farm animals (Abaurrea et al., 2006; Nienaber & Hahn, 2004).

The decision tree model (Figure 1) used to classify the heat waves that caused high broiler mortality presented 89.34% of accuracy and a high mortality class precision of 0.73.

In order to classify mortality rate among broilers, the model showed the maximum THI (Temperature and Humidity Index; Chepete et al., 2005) of the day as the root node, and then branched in two classification, according to broiler age in the high mortality classification.

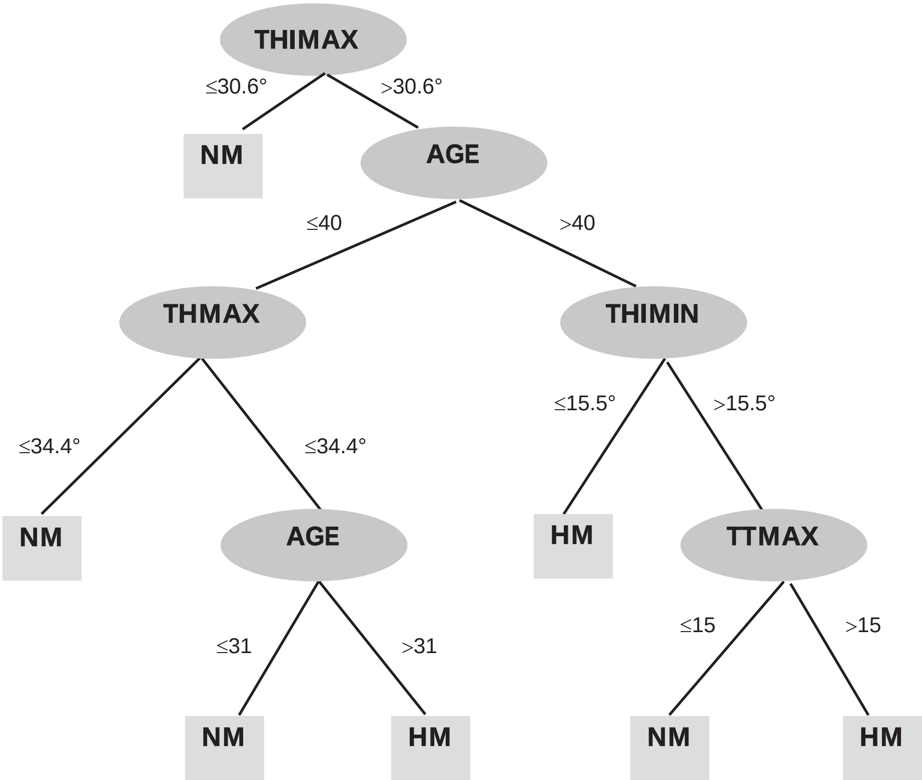
This of THI as root node is consistent with the findings of Vale et al. (2008), who obtained a decision tree with THI as root node to model broiler mortality in poultry houses with no environmental control. Ryder et al. (2004) also obtained similar correlation between thermal stress and production performance.

The attributes that are closer to the root node have stronger power of classification (Witten & Frank, 2005), and are more relevant to indicate days when there may be a heat wave.

In days with maximum THI below 30.6 °C, there was no high mortality among broilers living in poultry houses equipped with minimum environmental control (Figure 1).

The THI proposed by Chepete et al. (2005) is calculated based on dry and wet bulb temperatures, weighted as 75% and 25%, respectively, of total THI in degrees Celsius. Relative humidity close to 75% is normal in the studied region, as characterized by Chvatal et al. (1999). When THI is 30.6 °C, maximum air temperature is around 31 ºC, inversely calculated by psychrometric charts. This limit appears coherent with the data obtained by Vale et al. (2008) that shows the temperature of 32 ºC as the limit for mortality in poultry houses without environmental control.

On the other hand, maximum conditional THI above 30.6 °C indicates that maximum air temperature of




Legend: THIMAX, maximum daily temperature and humidity index in ºC; AGE days, broiler age in days; TMAX, maximum daily temperature ºC; THIMIN, minimum daily temperature and humidity index in ºC; TTMax, time occurrence of maximum daily temperature; NM, normal broiler mortality; HM, high broiler mortality.

**Figure 1** – Decision Tree for high broiler's mortality due to heat waves.

the day is between 31 ºC and 35 ºC. As a condition to classify high mortality, it is consistent with the findings of Abu-Dieyeh (2006), who showed that temperatures above 30 ºC may cause high mortality. Another justification for maximum THI may comfort temperature, which drops to approximately 24 ºC when broilers are older than four weeks of age (Teeter & Belay, 1996; Macari & Furlan, 2001; Cony & Zocche, 2004).

The construction of the decision tree in Figure 1, using THI and broiler age, agrees with the results of Ryder et al. (2004), These authors followed up 50 commercial broiler flocks, and found that stress index and bird age were the main causes of performance losses in two different regions.

No parameter in the model directly considered relative humidity, which is also an important factor of broiler comfort (Macari & Furlan, 2001; Tao & Xin, 2003; Genç & Portier, 2005; Chepete et al., 2005; Abu-Dieyeh, 2006; Menezes et al., 2010). This was probably due to data redundancy among or to lower classification power of relative humidity as compared to THI and other parameters.

The exclusion of features that are highly correlated before modeling is a technique applied during pre-processing of the data bank that allows increasing model accuracy (Oliveira et al., 2006).

However, the minimum THI of 15.5 ºC or lower, used in the model presented in Figure 1, when the maximum daily THI is higher than 30.6 ºC, causing high mortality in broilers with 40 days of age or older, indicates it is related with days of low relative humidity. During these days, temperature rapidly rises during the day, and also rapidly drops drop during the night, which is typical in the regions of the Brazilian Cerrado, a savannah.

There are no references on the occurrence of high mortality related to low temperatures during the night or to the thermal amplitude in broilers older than four weeks of age under stress caused by cyclical heat.

Due to the deficient thermal isolation of the poultry housed used in the present trial, which were similar to those studied by Moura (2001), internal house as sensitive to changes in the external environment, resulting in wide daily thermal amplitudes. It is reported that the use of roof insulation improves broiler performance during hot weather (Oliveira et al., 2000; Abreu et al., 2007); however, it does not severely affects the time of occurrence of either minimum or maximum air temperatures (Abreu et al., 2007).

In the present study, because broilers were exposed to low temperatures during the night, they may have benefited from the cooling effect of the decrease in temperature, similar to nocturnal ventilation, which improves broiler performance (Bottcher et al., 1994; Dozier et al., 2006). In the studied broiler houses, ventilation during the night was not used nor recommended by the company.

Low thermal inertia of the poultry houses was perhaps associated with broiler mortality. Further studies are needed to fully understand the evolution of the housing environment during heat waves. The lack of housing insulation, as observed by Moura (2001), may lead to rapid heating of the building during the day, not allowing birds enough time to improve their physiological responses and eventual acclimatization (Bukley et al., 2001; Horowitz, 2002). This type of temperature behavior during the day may, in some cases, increase mortality in the evening, which may explain the occurrence of high broiler mortality when birds are exposed to a single day of heat wave.

The use of nocturnal cooling using fans may not be advantageous when air temperature gradually increases during the growth period (Segura et al., 2006), but it may allow slow adaptation, decreasing the impact of temperature on mortality (Sykes & Fataftah, 1986). Studies on the incidence of heat waves along the year shall be carried out in order to provide better understanding of broilers acclimatization during extreme heat events.

Heat waves affected birds of different ages differently. There was no effect on the mortality rate of 29- to 31-day-old birds (Figure 1).

Another attribute of the model (Figure 1) used to classify high mortality was the bird age. High mortality incidence increased as birds aged. For birds between 31 and 40 days of age, Max THI above 30.6 °C and maximum temperature below 34.4 ºC were important factors for the occurrence of mortality in poultry houses with minimum environmental control.

The use of the bird age in the model (Figure 1) is consistent with the differences in the bird thermal tolerance, which occurs as birds grow (Lin et al., 2005). Thermal comfort temperatures between 32 ºC in the first week and 20 ºC in the sixth week of rearing are recommended (Teeter & Belay, 1996; Macari & Furlan, 2001; Cobb, 2008; Cony & Zocche, 2004; Lin et al., 2005).

The last attribute applied to build the model was the time of the day when temperature was maximal, and indicating weather conditions when temperature significantly rises during the day and continues to rise after 15:00h. Under this condition, the number of hours during which the birds are submitted to unfavorable environmental conditions may be decisive, particularly for birds older than 40 days, as discussed above (Macari & Furlan, 2001; Cony & Zocche, 2004; Lin et al., 2005; Abu-Dieyeh, 2006).

The time when temperature was maximal occurred even when this not happened repeatedly during consecutive days, demonstrating the possibility of the incidence of high mortality in a single day of extreme heat.

The model generated three main rules, as shown in Figure 1,to classify heat waves. In broilers between 31 and 40 days of age, maximum THI above 30.6 ºC and Max Temperature above 34.4 ºC cause high broiler mortality (Rule 1).

Rule 1 - IF THI Max > 30.6 ºC AND age ≥ 40 days AND T Max > 34.4º C AND age > 31 days THEN Class = HM

For broilers older than 40 days, maximum THI above 30.6 ºC and minimum THI 15.5 ºC or lower caused high broiler mortality (Rule 2).

Rule 2 - IF THI Max > 30.6 ºC AND age > 40 days AND THI Min ≥ 15.5 ºC THEN Class = HM

There was also high mortality in broilers older than 40 days when minimum THI was higher than 15.5 ºC and the time of maximum temperature was later than 15:00h (Rule 3).

Rule 3 - IF THI Max > 30.6 ºC AND age > 40 days AND THI Min > 15.5 ºC AND time to T Max > 15 hors THEN Class = HM

These rules may be applied to predict broiler mortality using the expected temperature and humidity for the next days and flock age. Decisions as to send flocks to slaughter may be guided by the possible occurrence of high broiler mortality, thereby reducing both performance and processing losses.

Research study need to be carried out to understand daily temperature dynamics during heat waves in order to predict them.

## CONCLUSIONS

A single hot days - a heat shock day - may cause high broiler mortality.

The classification of the mortality due to heat waves showed a model accuracy of 89.34% and a high-mortality class precision of 0.73 for 29-day-old to market-age broilers reared in poultry houses with minimum environmental control.

Heat waves affect birds of different ages differently. There was no impact of heat waves on broilers between 29 and 31 days of age.

Maximum THI above 30.6 ºC was the main feature of days presenting heat wave, increasing the mortality of broilers older than 31 days. Broilers between 31 and 40 days of age showed increased mortality when the maximum temperature of the day was above 34.4 ºC.

There were two critical conditions for high mortality of broilers older than 40 days:

1) Maximum THI above 30.6 ºC and minimum THI of 15.5 ºC or lower;
2) Maximum THI above 30.6 ºC, minimum THI above 15.5 ºC, and time of the maximum temperature later than 15:00 hours.

The heat waves that influenced broiler mortality lasted an average of 2.7 days.

## REFERENCES

Abaurrea J, Asin J, Cebrian AC, Centelles A. On the need of a changing threshold in heat wave definition. Geophysical Research Abstract 2006; 8:762-775.

Abreu PG, Abreu AC, Jaenish FRF, Paiva DP. Condições térmicas ambientais de aves criadas em aviários com e sem o uso d forro. Arquivos Brasileiros de medicina Veterinária e Zootecnia 2007; 59(4):1014-1020.

Abu-Dieyeh, ZHM. Effect of chronic heat stress and long-term feed restriction on broiler performance. International Journal of Poultry Science 2006; 5(2):185-190.

Bottcher RW, Bisesi PS, Brake J, Pardue SL, Etheredge AN. Educing mixing fan thermostat setpoint in naturally ventilated broiler house during hot weather. Journal Applied of Poultry Research 1994; 3:289-296.

Buckley BA, Owen M, Hofmann GE. Adjusting the thermostat: the threshold induction temperature for the heat- shock response in intertidal mussels (genus Mytilus) changes as a function of thermal history. The Journal of Experimental Biology 2001; 204:3571-3579.

Chapman P, Clinton J, Kerber R, Khabaza T, Reinartz T, Shearer C, Wirth R. CRISP-DM 1.0: step-by-step data mining guide. Ilinois: CRISP; 2000. 78p.

Chepete HJ, Chimbombi E, Tsheko R. Production performance and temperature-humidity index of Cobb 500 broilers reared in open-sided naturally ventilated houses in Botswana. Proceedings of the ASAE Annual Meeting; 2005. Beijing, China; 2005. p.701P0205.

Chvatal KMS, Labaki LC, Kowaltowski DCCK. Caracterização de climas compostos e proposições de diretrizes para o projeto bioclimático: o caso de Campinas. Anais do 2nd ELA CAC; 1999; Fortaleza, Ceará. Brasil. CD-Roon.

COBB. Broiler management guide. Cobb-Vantress, 2008. 65 p.

Cony AV, Zocche AT. Manejo de frangos de corte. In: Mendes AA, Nääs IA, Macari M. Produção de frangos de corte. Campinas, SP: FACTA; 2004. p. 117-136.

COPA/COGECA. Assessment of the impact of the heat wave and drought of the Summer 2003 on agricultural and forestry. Cologne: COPA/COGECA; 2004. 15 p.

Dozier WA, Purswell JL, Branton SL. Growth response of male broilers subjected to high air velocity for either twelve or twenty-four hours from thirty-seven to fifty-one days of age. Journal Applied of Poultry Research 2006; 15:362-366.

Genç L, Portier KM. Sensible and latent heat productions from broilers in laboratory conditions. Turkish Journal of Veterinary and Animal Sciences 2005; 29:635-643.

Gomes AK. Análise do conhecimento extraído de classificadores simbólicos utilizando medidas de avaliação e interessabilidade [dissertação]. São Carlos (SP): Universidade de São Paulo; 2002.

Horowitz M. From molecular and cellular to integrative heat defense during exposure to chronic heat. Comparative Biochemistry and Physiology. Part A 2002; 131:475-483.

INMET- Instituto Nacional de Meteorologia. Fenômenos adversos. Brasília: Ministério da Agricultura Pecuária e Abastecimento [citado 2010 maio 05 ] Disponível em: http://www.inmet.gov.br/html/informacoes/sobre_meteorologia/fenomenos_naturais/fenomenos_naturais.html.

Johnson HD. Aspects of animal biometeorology in the past and future. International Journal of Biometeorology 1997; 40:16-18.

Lin H, Zhang HF, Du R, Gu XH, Zhang ZY, Buyse J, Decuypere E. Thermoregulation response of broiler chickens to humidity at different ambient temperatures. II. Four weeks of age. Poultry Science 2005; 84:1173-1178.

Macari M, Furlan RL. Ambiência na produção de aves em clima tropical. In: Silva IJO, editor. Ambiência na produção de aves em clima tropical. Jaboticabal: Funep-Unesp; 2001. p.31-87.

Marengo JA. Relatório n° 1: Caracterização do clima no século XX e cenários climáticos no Brasil e na América do Sul para o século XXI derivados dos modelos globais de clima do IPCC. São Paulo: CPTEC/INPE; 2007. 182 p.

Menezes AG, Nääs IA, Baracho MS. Identification of critical points of thermal environment in broiler production. Brazilian Journal of

Poultry Research 2010; 12(1):1-21.

Moura DJ. Avaliação da eficiência térmica de instalações avícolas com diferentes orientações, sombreamento e ventilação [tese]. Campinas (SP): Universidade Estadual de Campinas; 1998.

Nääs IA, Romanini CEB, Salgado DD, Lima KAO, Vale MM, Labigalini MR, Souza SRL, Menezes AG, Moura DJ. Impact of global warming on beef cattle production cost in Brazil. Scientia Agricola 2010; 67(1):1-8.

Nienaber JA, Hahn GL. Engineering and management practices to ameliorate livestock heat stress [CD- ROM]. Proceedings of the International Symposium of the CIGR; 2004; Evora, Portugal.

Oliveira JE, Sakomura NK, Figueiredo N, Junior JL, Santos TMB. Efeito do isolamento térmico do telhado sobre o desempenho de frangos de corte alojados em diferentes densidades. Revista Brasileira de Zootecnia 2000; 29:1427-1434.

Oliveira SEM, Yamagishi MEB, Borro LC, Falcão PRK, Santos EH, Vieira FD, Mazoni I, Jardine JG, Nesich G. Uma metodologia para a seleção de parâmetros em modelos de classificação de proteínas. Boletim de Pesquisa e Desenvolvimento 2006; 14:1-18.

Quinlan JR. C4.5: Programs for machine learning. San Mateo, CA: Morgan Kaufmann Publishers; 1993. 302 p.

Quinlan JR. Improved use of continuous attributes in c4.5. Journal of Artificial Intelligence Research 1996; 4:77-90.

Robinson PJ. On the definition of a heat wave. Journal of Applied Meteorology 2001; 40(4):762-775.

Ryder AA, Feddes JJR, Zuidhof MJ. Field study to relate heat stress index to broiler performance. Journal Applied of Poultry Research 2004;13:493-499.

Segura JC, Feddes JJR, Zuidhof MJ. Midday and nighttime cooling of broiler chickens. Journal Applied of Poultry Research 2006; 15:28-39.

Smith DP, Northcutt JK. Pale poultry muscle syndrome. Poultry Science 2009; 88:1493-1496.

St-Pierre NR, Cobanov B, Schnitkey G. Economic losses from heat stress by livestock industries. Journal of Dairy Science 2003; 86(E):52-77.

Sykes AH, Fatafah ARA. Acclimatisation of the fowl to intermittent acute heat stress. British Poultry Science 1986; 27:289-300.

Tabler GT, Berry IL, Xin H, Bartons TL. Spatial death losses in broiler flocks. Journal Applied of Poultry Research 2002; 11:388-396.

Tao X, Xin H. Temperature-humidity-velocity: index for market-size broilers. ASAE Annual Meeting; 2003; Las Vegas. USA. Paper n. 034037.

Teeter RG, Smith MO, Owens FN, Arp SC, Sangiah S, Breazile E. Chronic heat stress and respiratory alkalosis: occurrence and treatment in broiler chicks. Poultry Science 1985; 64:1060-1064.

Teeter RG, Belay T. Broiler management during acute heat stress. Animal Feed Science and Technology 1996; 38:127-142.

Tinoco IFF. A granja de frangos de corte. In: Mendes AA, Nääs IA, Macari M. Produção de frangos de corte. Campinas, Brazil: FACTA; 2004. p. 55-84.

Vale MM, Moura DJ, Nääs IA, Oliveira SR, Rodrigues LHA. Data mining to estimate broiler mortality when exposed to heat wave. Scientia Agricola 2008; 65(3):223-229.

Witten IH, Frank E. Data mining: practical machine learning tools and techniques. 2nd ed. San Francisco: Morgan Kaufmann; 2005. 525 p.

Yahav S, Goldfeld S, Plavnik I, Hurwitz S. Physiological response of chickens and turkeys to relative humidity during exposure to high ambient temperature. Journal of Thermal Biology 1995; 20:245-253.