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Modeling preslaughter mortality of broiler chickens using double generalized linear models

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ABSTRACT

The aim of this study was to estimate parameters and design models for mortality prediction of broiler chickens in different preslaughter conditions, using the double generalized linear models. Preslaughter data from 13,937 broiler flocks were recorded daily during 2006, in a commercial slaughterhouse in Brazil. Several factors which influenced mortality rate were analysed, such as daily mean dry-bulb temperature and relative humidity, lairage time, daily periods, density of broilers per crate and season of the year. The data were analysed using a Double Generalized Linear Model, an extension of Generalized Linear Models (GLM), which provides a framework for modeling the dispersion in generalized linear models as well as the mean. As results, the double generalized linear models showed high accuracy for broiler mortality estimation, through interactions between the main factors which have influence on preslaughter operations.

Key words: poultry production, preslaughter operations, stochastic models

Modelización de la mortalidad previo al sacrificio de pollos con modelos lineales generalizados doble

RESUMEN

El objetivo de este estudio fue estimar parámetros y diseñar modelos para predecir la mortalidad de pollos de engorde en distintas condiciones de pre abate, utilizándose de un modelo linear generalizado doble. Datos del pre abate de 13.937 pollos fueron colectados diariamente durante el año de 2006 en un matadero comercial en Brasil. Distintos factores que tienen influencia sobre la tasa de mortalidad fueron analizados, como la media de temperatura de bulbo seco y humedad relativa del aire, tiempo de estabulación, periodos diarios, densidad de los pollos por caja y estaciones del año. Los datos fueron analizados utilizándose del Modelo Linear Generalizado Doble, una extensión del Modelo Linear Generalizado (MLG), que proporciona un marco para el modelado de la dispersión en los modelos lineares generalizados y también la media. Como resultado, el modelaje linear generalizado doble demostró una alta precisión para estimar la tasa de mortalidad de pollos de engorde, a través de las interacciones entre los principales factores que influyen en las operaciones antes del abate de los animales.

Palabras clave: modelos estocásticos, operaciones previas al sacrificio, producción avícola

Introduction

The concern about reducing losses throughout the poultry production chain has been rising in the last years. However, the climatic challenges and the consumer's market pressure regarding animal welfare oblige the sector to search for critical points in the production process. The preslaughter operations are one of the major problems in the poultry industry, responsible for more than 1% losses before slaughtering, which represent millions of dollars lost per year (Ritz et al., 2005). Accordingly to Silva & Vieira (2010), the acceptable proportion of dead birds during preslaughter operations is between 0.1 and 0.5%.

Numerous factors might contribute to stress and posteriorly with increasing mortality of these animals in transit, as well as distance between farms and slaughterhouse (Vieira et al., 2010a), thermal conditions during transport (Barbosa Filho et al., 2009), vibration on load (Abeyesinghe et al., 2001), density of birds per cage (Delezie et al., 2007), feed withdrawal and social disruption (Nicol & Scott, 1990). Despite previous studies regarding these main variables which determine the preslaughter losses, it was observed that few studies discussed the joint approach of these factors. Given the complexity and the range of factors involved in mortality assessment, more robust stochastic models should be considered (Santoro et al., 2003).

The poultry mortality might be treated as proportion. For the analysis of this response variable, a suitable alternative is the use of Generalized Linear Models (GLM), by which measures are modeled using probabilistic distributions belonging to exponential family, such as Poisson and Binomial (Nelder & Wedderburn, 1972). This fact is very important for preslaughter operations, once that the mortality per truck is a rare event, that is, below 3% in a contingent of approximately 3,500 birds transported in a road vehicle. However, due to non included variables which have influence in mortality, the variability can be higher than the observed mean and consequently results in the overdispersion phenomenon. This problem causes p-values highly significant, which reduce the analysis accuracy (Hinde & Demétrio, 1998; Vieira et al., 2010b). An alternative developed by Smyth (1989) is the Double Generalized Linear Models (DGLM), which consist in an extension of GLM's which model simultaneously the data mean and dispersion. This model class has potential use in studies of livestock mortality. Thus, the aim of this study was to estimate parameters and design models for mortality prediction of broiler chickens in different preslaughter conditions, using the double generalized linear models.

Material and Methods

The study was carried out in a commercial slaughterhouse. During 2006, the preslaughter mortality dataset of 13,937 transport vehicles was recorded. The variables related with catching, crating, transport and lairage at the slaughterhouse were recorded throughout the study. The climate is humid subtropical according with Köppen classification, characterized by a warm and wet season from October to March (mean temperature above 22°C) and a dry season from June to August (mean temperature approximately 18°C; Pereira et al., 2002).

The processing plant slaughters on average 190,000 broiler chickens per day. The slaughtering started daily at 5:30 am and ended at 3:30 am. The broiler chickens were loaded in crates of plastic material, with perforated walls and floor for ventilation. Each crate had a maximum stocking density of 10 birds (450 cm² per bird). On arrival at the slaughterhouse, the truck with broilers were lairaged in a variable time inside of a holding area with capacity of 8 trucks, with environmental acclimatization achieved by fans intercalated with sprinklers (Figure 1).

Figure 1. The holding area with trucks of the studied poultry slaughterhouse

The transported birds came from commercial farms of the region and varied in genotype (Ross or Cobb), gender and slaughter age (from 6 to 7 weeks). The animals had an mean live weight of about 2.5 kg. Before the chickens being caught and crated, feed and water were removed and the length of the feed withdrawal period was 8 hours, included all preslaughter operations (catching, crating, transport and lairage at the slaughterhouse). The broiler flock was considered as the total of broiler chickens transported on commercial vehicles.

For each broiler flock, the following variables were assessed: environment dry-bulb temperature (°C) and relative humidity (%), lairage time (hours), daily periods (categorical factors considered as dummy variable - morning, afternoon and night), distance (transport distance between farm and slaughterhouse), crating density (number of birds per crate), season of year (summer: January to March; autumn: March to June; winter: June to September; spring: September to December) and broiler mortality per truck (%). Daily dry-bulb temperature and relative humidity was collected at 1-h intervals from the weather station in the city, near the slaughterhouse (22º01'03''S, 47º53'27''W; 856 m above sea level).

The assessed mortality for each transported flock at the slaughterhouse was considered as the percentage of dead birds in relation with the total of birds transported per truck, identified at the point of live hanging from shackles on the slaughter line.

For an overall descriptive statistics analysis, values of mean, standard deviation, and coefficient of variation of daily dry-bulb temperature and relative humidity were used, as well as for the preslaughter factors.

The data were analyzed using a Double Generalized Linear Model, an extension of Generalized Linear Models (GLM), which provides a framework for modeling the dispersion in generalized linear models as well as the mean. The variance $Var(Y) = \varphi V(\mu)$ was considered in two components: a variation dependent of mean ($V(\mu)$) and another variation independent of mean (φ). According to Smyth and Verbyla (1999), GLM traditionally considers that the mean μ_i can be modeled by a link-linear relationship (1):

$$g(\mu_i) = x_i^T \beta \quad (1)$$

where $g(\cdot)$ is a logarithmic function, to make a link between model linear predictor and expected value of preslaughter mortality, treated as a response variable with Poisson distribution. The vector β contains the unknown regression coefficients of the explanatory factors.

Double generalized linear models assume a second link-linear prediction for the dispersion (2):

$$h(\phi_i) = z_i^T \lambda \quad (2)$$

where h is another known link function and z_i is a vector of covariates and/or factors affecting the dispersion. Also, the link function $h(\cdot)$ was assumed as a logarithmic function, which guarantees positive values for the expected dispersion parameter φ. This approach allows applying all the techniques of residual analysis and diagnosis for the class GLM, to verify the goodness of fit. The Wald statistic was used with the objective of testing the hypothesis about the vector β, that is, to test the true contribution of these factors and interactions on the statistical model (Knight, 2000). This test is an extension of the Student's t test, commonly used in the general linear regression analysis. Complementary to the Wald test, a residual analysis was performed, to verify the model assumptions, based on deviance residuals, fitted values, q-q plots, scale-location plot and Cook's distance, widely used in GLM analysis (McCullagh and Nelder, 1989).

For the categorical factors (daily periods and seasons), the dummy coding with three or more levels of categorical variables was used. These factors were converted into two or three dichotomous variables, whereas the estimated mean of the third or fourth variable (omitted or reference group) is the intercept term of the model. This explains the absence of the reference group in the fitted model, but implicitly, their underlying effects are jointly adjusted with the others factor levels in the statistical analysis. In this study, the reference group for daily periods was the level *morning* and for seasons, the level *summer*.

The statistical software R (R Development Core Team, 2006) was used for estimation, joint to the *dglm* library (Dunn & Smyth, 2006). This algorithm differs from the approach described by Smyth (1989) and Nelder & Lee (1991). Improvements on the approximation of the data distribution and bias reduction of the estimates of γ were proposed (Smyth & Verbyla, 1999).

Results and Discussion

In this present study, the highest variations regarding preslaughter factors were observed for lairage time, distance between farms and slaughterhouse and mortality before arrival at the processing plant (Table 1).

Table 1. Mean, standard deviation (SD), minimum and maximum values of preslaughter variables of the slaughterhouse dataset

Preslaughter variable	Mean ± SD	Minimum	Maximum
Density of birds per crate	7.0 ± 0.9	4.0	10.0
Lairage time (hours)	02:58 ± 01:37	00:00	17:38
Transport time (hours)	01:30 ± 00:58	00:20	04:00
Transport distance (km)	120.0 ± 68.4	24.0	242.0
Preslaughter mortality (%)	0.33 ± 0.87	0.00	10.88

The recorded average lairage time was at an acceptable level of welfare and thermal comfort of birds, as reported by Silva & Vieira (2010), considering the use of environment control inside the holding area. However, the amplitude of time interval was around 17 hours, which indicates possible problems related to lairage time control during the year. The average distance between farms and the slaughterhouse was >100 km, whereas the maximum distance was 240 km. Jorge (2008) found a mortality of 1.31% associated to distance of around 250 km. Thus, the distance variation registered in this study is considered aversive with respect to welfare of birds in transit and final product quality (Oba et al., 2009; Nielsen et al., 2011). Regarding the mortality, the average found in this study is around the limit of 0.20% recommended by Ritz et al. (2005). However, the lairage time, the amplitude evidenced some situations which justify the importance of this assessment, once that 30% of loads showed mortality above 1.0%.

About the thermal condition observed during 2006, the most critical period for broiler transport was the afternoon, with mean temperature of 25.2 °C, with maximum of 33°C (Table 2).

Although the mean temperature is in the comfort range for birds (Macari & Furlan, 2001), the difference between crating temperature and the external environment may reach 10 °C in the hottest hours (Hunter, 1998). The results of the present

Table 2. Descriptive statistics of environmental condition during the study

Variables	Period	Mean ± SD	CV (%)	Minimum	Maximum
Temperature (ºC)	Morning	20.3 ± 3.0	15	11.0	27.0
	Afternoon	25.2 ± 3.0	12	18.0	33.0
	Night	18.1 ± 3.0	17	9.0	25.0
Relative Humidity (%)	Morning	80 ± 11	14	55	96
	Afternoon	63 ± 17	27	21	95
	Night	86 ± 10	12	85	95

[SD] Standard deviation; [CV] Coefficient of variation.

study are in accordance with Vieira et al. (2011), who reported that the daily periods with temperature a >25 °C are the harsh periods for transportation, with respect to thermal comfort ranges for broiler chickens. During morning and night, the temperature was below the thermal comfort range of birds, either considering the thermal gradient between the crates and external environment. These results are in agreement with Barbosa Filho et al. (2009), who found lowest thermal loads inside crates in these periods and a small difference of temperature between inside and outside crates around 2.4 °C.

Based on the relationship between mortality and the covariates present in the preslaughter operations, 12 models were adjusted in this study (Table 3).

The analysis resulted in models with highly significant interactions (P<0.05). Considering that this dataset should not be treated as a sample, but like as a population of all transports (13.937 transports), the observed variability is higher than the observed mean, resulting in overdispersion. Furthermore, accordingly to Smyth and Verbyla (1999), for the modeling of sample which shows overdispersion, the dispersion modeling becomes mandatory with the objective to become more efficient the estimation of mean parameters when dispersion is too variable. In this case, Smyth (1989) related that the known models have low efficiency, such as the GLM's, quasi-Poisson, angular transformation, among others.

Comparing several models used for swine natimortality estimation, Santoro et al. (2003) reported that the best adjusted model was the GLM with binomial distribution and logit link function, based on residual analysis and predictive accuracy. However, the same authors affirmed that such classes of models are limited when the errors are not normally distributed, such as binary mortality data. Also, they concluded that the presence of non-measured factors helps in a better adjusted model. As is shown in the study of Vieira (2008), the ordinary GLM resulted in standard errors excessively small when overdispersion of data occurs, as compared with quasi-Poisson model, for example. Additionally, comparing the quasi-Poisson model with DGLM, the first was more restrictive with reference to dispersion, because this class of models only adjusts the estimated standard error (Nelder & Pregibon, 1987). The DGLM accommodates a high variability through mean estimation based upon dispersion models anteriorly adjusted. That is, such approach better refine the mean model in case of overdispersion generated by non-controlled factors in mortality studies (Smyth, 1989; Vieira et al., 2010b).

A great contribution of DGLM is the information generated by dispersion model, as evidenced below:

$$\hat{\phi} = \exp\left(2.79^{*} + 34.12t_o + 26.15t_o^2 + 9.88t_o^3 - \right.$$
$$\left. - \; 0.08^{ns}a + 0.15^{*}n - 1.29^{*}f - 0.56^{*}i - 0.61^{*}p\right) \quad (3)$$

where t_o, t_o^2, t_o^3 = 3rd degree polynomial factor for daily mean dry-bulb temperature (°C); a = afternoon; n = night; f = autumn; i = winter; p = spring; ^{NS} non-significant; * significant difference (p<0.005), derived by Wald test.

The season of the year and daily dry-bulb temperature had major influence on mortality variability. For dispersion model, the external temperature was modeled through orthogonal polynomial, with the aim of to minimize the ill-conditioning in the numeric process of estimation. Afternoon reduced the variability in the number of dead birds compared with morning. This is expected, because afternoon during the most part of the year show inadequate thermal conditions for broiler transportation, maintaining high mortality rates in this period, which reduces the variability due to low frequency of situations with temperature and relative humidity in the thermal comfort range for broiler chickens (Baker et al., 1994; Petracci et al., 2006; Simões et al., 2009).

For exemplification of these models used for preslaughter mortality prediction, the Figure 2 evidence the interaction between dry-bulb temperature and lairage time at the slaughterhouse.

It is possible to observe that when dry-bulb temperature was in the thermal comfort range (below 21°C), the environment control allied to lairage time did not show effect on preslaughter loss reduction. However, the major effect of the environment control inside the holding area was verified for temperatures above 29 °C, considered aversive from the welfare point of view. In these conditions, birds are more sensitive to the thermal treatment through the use of fans and sprinklers and thus, they return to the prior thermal comfort state as the exposition time to the environment control increase, that is, with the rise of lairage time. These results are in agreement with previous results of Furlan et al. (2000), who reported the reduction of body temperature of birds from the first 10 minutes of exposition to forced ventilation, when the air temperature was above 29 °C. Bayliss & Hinton (1990) found mortality rates around 0.2% when evaporative cooling systems (ventilation and sprinkling) were used in the holding

Table 3. Double generalized linear models for preslaughter mortality of broilers

Factors and/or interactions	Models[1]	P-value
Density per cage × Night	$\hat{y} = \exp(-5.01 \cdot 10^{-2} + 0.25d + 0.19n - 0.14dn)$	$3.27 \cdot 10^{-9}$
Density per cage × Afternoon	$\hat{y} = \exp(-5.01 \cdot 10^{-2} + 0.25d + 7.14 \cdot 10^{-4}a - 7.68 \cdot 10^{-2}da)$	$5.05 \cdot 10^{-3}$
Temperature × Night	$\hat{y} = \exp(-5.01 \cdot 10^{-2} + 3.25 \cdot 10^{-2}t + 0.19n + 3.28 \cdot 10^{-2}tn)$	$6.34 \cdot 10^{-5}$
Lairage time × Afternoon	$\hat{y} = \exp(-5.01 \cdot 10^{-2} + 4.0 \cdot 10^{-3}e + 7.14 \cdot 10^{-4}a + 1.24 \cdot 10^{-3}ea)$	$4.21 \cdot 10^{-5}$
Lairage time × Night	$\hat{y} = \exp(-5.01 \cdot 10^{-2} + 4.0 \cdot 10^{-3}e + 0.19n + 8.51 \cdot 10^{-4}en)$	$1.48 \cdot 10^{-4}$
Autumn × Night	$\hat{y} = \exp(-5.01 \cdot 10^{-2} - 0.71f + 0.19n + 0.24fn)$	$2.56 \cdot 10^{-4}$
Winter × Night	$\hat{y} = \exp(-5.01 \cdot 10^{-2} - 0.49i + 0.19n + 0.46in)$	$1.46 \cdot 10^{-10}$
Spring × Night	$\hat{y} = \exp(-5.01 \cdot 10^{-2} - 0.26p + 0.19n + 0.30pn)$	$4.73 \cdot 10^{-7}$
Density per cage × Lairage time	$\hat{y} = \exp(-5.01 \cdot 10^{-2} + 0.25d + 4.0 \cdot 10^{-3}e - 5.13 \cdot 10^{-4}de)$	$2.48 \cdot 10^{-7}$
Temperature × Lairage time	$\hat{y} = \exp(-5.01 \cdot 10^{-2} + 3.25 \cdot 10^{-2}t + 4.0 \cdot 10^{-3}e - 9.63 \cdot 10^{-5}te)$	$5.00 \cdot 10^{-3}$
Autumn × Lairage time	$\hat{y} = \exp(-5.01 \cdot 10^{-2} - 0.71f + 4.0 \cdot 10^{-3}e + 1.04 \cdot 10^{-3}fe)$	$3.28 \cdot 10^{-4}$
Relative Humidity	$\hat{y} = \exp(-5.01 \cdot 10^{-2} + 4.02 \cdot 10^{-3}u)$	$3.50 \cdot 10^{-7}$

[1] $\hat{y}$: expected mean parameter; d: density of birds per cage; n: night; a: afternoon; t: dry-bulb temperature; e: lairage time; f: autumn; i: winter; p: spring; u: relative humidity.

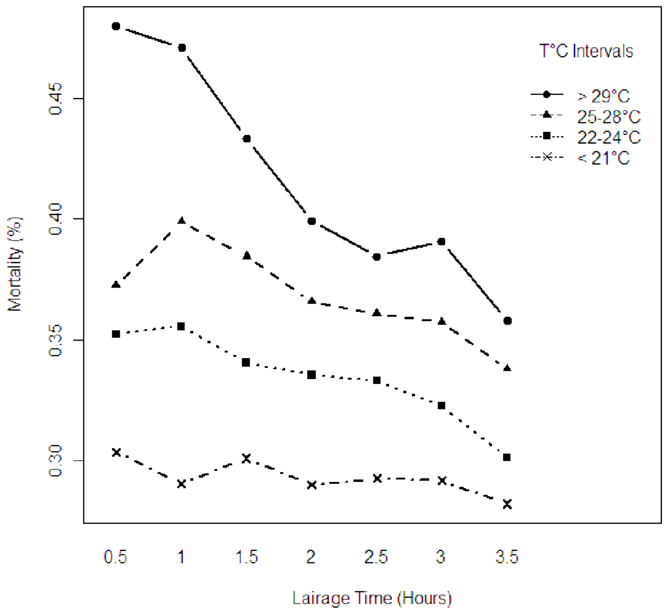

Figure 2. Interaction plot between lairage time intervals (hours) and dry-bulb temperature intervals (°C) and its effects on preslaughter mortality (% per truck) of broiler chickens

area. However, only the environment control is insufficient to reduce the thermal load of crated birds, requiring a time interval above 2 hours which allow the heat dissipation of the animals to the environment (Quinn et al., 1998).

Conclusions

The double generalized linear models showed high accuracy for broiler mortality estimation, through interactions between the main factors which have influence on preslaughter operations. This efficiency was characterized by the reduction of parameter's standard error estimate and confirmed through significant probability obtained in this study.

Literature Cited

Abeyesinghe, S. M.; Wathes, C. M.; Nicol, C. J.; Randall, J. M. The Aversion of Broiler Chickens to Concurrent Vibrational and Thermal Stressors. Applied Animal Behaviour Science, v.73, n.3, p.199-215, 2001. <http://dx.doi.org/10.1016/S0168-1591(01)00142-3>.

Baker, C. J. Aerodynamics of poultry transporters: implications for environmental control. World's Poultry Science Journal, v.50, n.1, p.62-63, 1994. <http://dx.doi.org/10.1079/WPS19940008>

Barbosa Filho, J. A. D.; Vieira, F. M. C.; Silva, I. J. O.; Garcia, D. B.; Silva, M. A. N.; Fonseca, B. H. F. Transporte de frangos: caracterização do microclima durante o inverno. Revista Brasileira de Zootecnia, v.38, n.12, p.2442-2446, 2009. <http://dx.doi.org/10.1590/S1516-35982009001200021>.

Bayliss, P. A.; Hinton, M. H. Transportation of broilers with special reference to mortality rates. Applied Animal Behavior Science, v.28, n.1, p.93-118, 1990. <http://dx.doi.org/10.1016/0168-1591(90)90048-I>.

Delezie, E.; Swennen, Q.; Buyse, J.; Decuypere, E. The effect of feed withdrawal and crating density in transit on metabolism and meat quality of broilers at slaughter weight. Poultry Science, v.86, n.7, p.1414-1423, 2007. <http://dx.doi.org/10.1093/ps/86.7.1414>.

Dunn, P. K.; Smyth, G. K. DGLM: Double generalized linear models. R package version 1.6.1., 2006. <http://cran.r-project.org/web/packages/dglm/index.html>. 20 Nov. 2010.

Furlan, R. L.; Macari, M.; Secato, E. R.; Guerreiro, J. R.; Malheiros, E. B. Air velocity and exposure time to ventilation affect body surface and rectal temperature of broiler chickens. Journal of Applied Poultry Research, v.9, n.1, p.1-5, 2000. <http://dx.doi.org/10.1093/japr/9.1.1>.

Hinde, J.; Demétrio, C. G. B. Overdispersion: models and estimation. Computational Statistics Data & Analysis, v.27, n.2, p.151-170, 1998. <http://dx.doi.org/10.1016/S0167-9473(98)00007-3>.

Hunter, R. R. Physiological responses of broilers to pre-slaughter lairage: effects of the thermal micro-environment? British Poultry Science, v.39, suppl.001, p.53-54, 1998. <http://dx.doi.org/10.1080/00071669888377>.

Jorge, P. S. Avaliação do bem-estar durante o pré-abate e abate e condição sanitária de diferentes segmentos da cadeia avícola. Jaboticabal: Universidade Estadual Paulista "Júlio de Mesquita Filho", 2008. 107p. Tese Doutorado. <http://www.fcav.unesp.br/download/pgtrabs/mvp/d/401.pdf>. 21 Ago. 2011.

Knight, K. Mathematical statistics. Boca Raton: Chapman and Hall, 2000. 504p.

Macari, M.; Furlan, R. L. Ambiência na produção industrial de aves em clima tropical. In: Silva, I. J. O. (Ed.). Ambiência na produção industrial de aves em clima tropical. Piracicaba: FUNEP, 2001. p.146-164.

McCullagh, P.; Nelder, J. A. Generalized linear models. London: Chapman and Hall, 1989. 532p.

Nelder, J. A.; Lee, Y. Generalized linear models for the analysis of Taguchi-type experiments. Applied Stochastic Models and Data Analysis, v.7, n.1, p.107-120, 1991. <http://dx.doi.org/10.1002/asm.3150070110>.

Nelder, J. A.; Pregibon, D. An extended quasi-likelihood function. Biometrika, v.74, n.2, p.221-232, 1987. <http://dx.doi.org/10.1093/biomet/74.2.221>.

Nelder, J. A.; Wedderburn, W. M. Generalized Linear Models. Journal of The Royal Statistical Society A, v.135, n.3, p.370-384, 1972. <http://dx.doi.org/10.2307/2344614>.

Nicol, C. J.; Scott, G. B. Pre-slaughter handling and transport of broiler chickens. Applied Animal Behaviour Science, v.28, n.1-2, p.57-73, 1990. <http://dx.doi.org/10.1016/0168-1591(90)90046-G>.

Nielsen, B. L.; Dybkjær, L.; Herskin, M. S. Road transport of farm animals: effects of journey duration on animal welfare. Animal, v.5, n.3, p.415-427, 2011. <http://dx.doi.org/10.1017/S1751731110001989>.

Oba, A.; Almeida, M.; Pinheiro, J. W.; Ida, E. I.; Marchi, D. F.; Soares, A. L.; Shimokomaki, M. The effect of management of transport and lairage conditions on broiler chicken breast meat quality and doa (death on arrival). Brazilian Archives of Biology and Technology, v.52, n.special, p.205-211, 2009. <http://dx.doi.org/10.1590/S1516-89132009000700026>.

Pereira, A. R.; Angelocci, L. R.; Sentelhas, P. C. Agrometeorologia: fundamentos e aplicações práticas. Guaíba: Agropecuária, 2002. 478p.

Petracci, M.; Bianchi, M.; Cavani, C.; Gaspari, P.; Lavazza, A. Preslaughter mortality in broiler chickens, turkeys and spent hens under commercial slaughtering. Poultry Science, v.85, n.9, p.1660-1664, 2006. <http://dx.doi.org/10.1093/ps/85.9.1660>.

Quinn, A. D.; Kettlewell, P. J.; Mitchell, M. A.; Knowles, T. Air movement and the thermal microclimates observed in poultry lairages. British Poultry Science, v.39, n.4, p.469-476, 1998. <http://dx.doi.org/10.1080/00071669888610>.

R Development Core Team. R: a language and environment for statistical computing, 2006. <http://www.r-project.org/>. 10 Nov. 2010.

Ritz, C. W.; Webster, A. B.; Czarick, M. Evaluation of hot weather thermal environment and incidence of mortality associated with broiler live haul. Journal of Applied Poultry Research. v.14, n.3, p.594-602, 2005. <http://dx.doi.org/10.1093/japr/14.3.594>.

Santoro, K. R., Barbosa, S. B. P.; Holanda, M. C. R. Modelos de predição da natimortalidade em suínos. Revista Brasileira de Zootecnia, v.32, n.5, p.1131-1140, 2003. <http://dx.doi.org/10.1590/S1516-35982003000500013>.

Silva, I. J. O.; Vieira, F. M. C. Ambiência animal e as perdas produtivas no manejo pré-abate: o caso da avicultura brasileira. Archivos de Zootecnia, v.59, n.225, p.113-131, 2010. <http://www.uco.es/organiza/servicios/publica/az/php/img/web/08_11_34_1869REVISIONAmbienciaSilva.pdf>. 22 Ago. 2011.

Simões, G. S.; Oba, A.; Matsuo, T.; Rossa, A.; Shimokomaki, M.; Ida, E. I. Vehicle thermal microclimate evaluation during Brazilian summer broiler transport and the occurrence of PSE (pale, soft, exudative) meat. Brazilian Archives of Biology and Technology, v.52, n.special, p.195-204, 2009. <http://dx.doi.org/10.1590/S1516-89132009000700025>.

Smyth, G. K. Generalized linear models with varying dispersion. Journal of The Royal Statistical Society B, v.51, n.1, p.47-60, 1989. <http://www.jstor.org/discover/10.2307/2345840?uid=2&uid=4&sid=21101735634167>. 22 Ago. 2011.

Smyth, G. K.; Verbyla, A. P. Adjusted likelihood methods for modeling dispersion in generalized linear models. Environmetrics, v.10, n.6, p.695-709, 1999. <http://dx.doi.org/10.1002/(SICI)1099-095X(199911/12)10:6<695::AID-ENV385>3.0.CO;2-M>.

Vieira, A. M. C. Modelagem simultânea de média e dispersão e aplicações na pesquisa agronômica. Piracicaba: Escola Superior de Agricultura “Luiz de Queiroz”. Piracicaba, 2008. 117p. Tese Doutorado. <http://www.teses.usp.br/teses/disponiveis/11/11134/tde-10032009-082556/pt-br.php>. 22 Ago. 2011.

Vieira, A. M. C.; Leandro, R. A.; Demétrio, C. G. B.; Molenberghs, G. Double generalized model for tissue culture proportion data: a bayesian perspective. Journal of Applied Statistics, v.38, n.8, p.1717-1731, 2010b. <http://dx.doi.org/10.1080/02664763.2010.529875>.

Vieira, F. M. C.; Silva, I. J. O.; Barbosa Filho, J. A. D.; Vieira, A. M. C. Productive losses on broiler preslaughter operations: effects of the distance from farms to abattoirs and of lairage time in a climatized holding area. Revista Brasileira de Zootecnia, v.39, n.11, p.2471-2476, 2010a. <http://dx.doi.org/10.1590/S1516-35982010001100021>.

Vieira, F. M. C.; Silva, I. J. O.; Barbosa Filho, J. A. D.; Vieira, A. M. C.; Rodrigues-Sarnighausen, V. C. Thermal stress related with mortality rates on broiler’s preslaughter operations: a lairage time effect study. Ciência Rural, v.41, n.9, p.1639-1644, 2011. <http://dx.doi.org/10.1590/S0103-84782011005000111>.