

Use of thermography for the evaluation of the surface temperature of Japanese Quail submitted at different temperatures

J.O. Castro¹, T. Yanagi Junior¹, A.L. Abreu², P.F.P. Ferraz¹, G.B. Moura¹,
D. Cecchin^{3,*} and L. Conti⁴

¹Federal University of Lavras, Agricultural Engineering Department, Campus Universitário, PO Box 3037 Lavras, Minas Gerais, Brazil

²Federal University of Lavras, Agricultural Department, Campus Universitário, PO Box 3037 Lavras, Minas Gerais, Brazil

³Federal University Fluminense, Department of Agricultural Engineering and Environment, Campus Praia Vermelha, São Domingos, Niterói, BR24.210-240 Rio de Janeiro, Brazil

⁴University of Firenze, Department of Agriculture, Food, Environment and forestry (DAGR), Via San Bonaventura, 13, IT50145 Firenze, Italy

*Correspondence: patricia.ponciano@ufla.br

Abstract. Thermography has been gaining more space in analyzes of the superficial thermal profile of birds since it is a non-invasive way of evaluating thermal comfort. This study aims to evaluate the influence of different air temperatures (t_{air}) from 20 °C to 32 °C on the maximum, average and minimum surface temperature (ST_{max} , $ST_{average}$ and ST_{min}) of Japanese laying quails. The experiment was performed in four wind tunnels, where the continuous air temperature within each tunnel, 20 °C, 22 °C, 24 °C, 26 °C, 28 °C, 30 °C and 32 °C represented treatment, with 20 °C being the control treatment. Two experiments, of 21 days each, were carried out. For each experiment, we used four replicates and eight quails in each repetition, in a completely randomized design. Thermographic images of each repetition were made weekly through the Fluke Ti55 camera and analyzed using SmartView[®] software. The ST_{max} , $ST_{average}$ and ST_{min} of each repetition were obtained by delimiting the area of the quails within the cages. Significant differences were observed between ST as the room temperature increased. The ST of quails behaved similarly from 28 °C on. Both head and feet had higher temperatures. It was possible to verify that air temperatures above 22 °C promoted an increase in the maximum, average and minimum surface temperatures. The highest surface temperatures are found in the head and foot region.

Key words: thermal comfort, quail farming, thermal image.

INTRODUCTION

Currently, quail farming in Brazil has shown rapid growth due to economic requirements in poultry. Poultry farming has been promoting competitiveness in the international food market and stimulating the emergence of small and large scale animal

production systems (IBGE, 2017), offering to the country a high profitable index, due to the growth in consumption of poultry derived food.

In recent decades farmers have sought different ways to improve and increase production. Understanding how quails react to the environment becomes an essential point to achieve efficiency and productivity in the poultry chain. An increase in the number of research regarding the control of the thermal environment was observed. This control has become extremely necessary so that the animals can express their full potential productive (Cassuce et al., 2013; Cândido, 2016). Knowledge of the environment is essential for the maintenance of bird homeothermy and a drastic change in the environment can cause significant losses in the production of these animals since it has a direct effect on their physiology. As a consequence of the elevation of the room temperature, the birds can increase the respiratory rate (Castilho et al., 2015), increase water consumption and reduce feed consumption and consequently affect their performance (Santana et al., 2018).

According to Oliveira (2014), poultry performance, nutrient consumption, weight gain and mortality are influenced by thermal comfort in the first three weeks of life. Therefore, the environmental temperature control is crucial so that hyperthermia, low productivity and mortality of these animals will not occur (Mashaly et al., 2004).

Being aware that environmental control is not only necessary but a condition for high productivity indexes, the thermographic analysis allows the monitoring of animal superficial temperature and the evaluation of variation (Ferreira, 2016; Silva et al., 2017). This variation in surface temperature can give us information about the comfort conditions of the animals.

One of the main impediments to quantifying sensible heat loss was the inability to accurately measure animal surface temperature distribution and to differentiate heat loss of different surface regions (Yahav et al., 2004).

Nowadays, thermographic analysis is one of the most accurate techniques of non-contact temperature measurement, allowing an analysis based on non-destructive tests using cameras and infrared sensors to measure temperature and heat distribution. It is a non-invasive technique to visualize the thermal profile of the animal (or object), enabling the information as infrared radiation (Carvalho et al., 2011; Nascimento et al., 2011).

Due to its positive characteristics, thermographic analysis to evaluate the surface temperature of cattle (Roberto & Souza, 2014), pigs (Pulido-Rodriguez et al., 2017) and poultry has been used (Abreu et al., 2017).

The evaluation of the animal surface temperature can be used as an index to accurately estimate the physiological state of an animal in conditions of stress, fertility, welfare, metabolism, health and disease detection. The surface temperatures are processed by computer and displayed as a thermal map over the animal, which provides a detailed analysis of the temperature profile (McManus et al., 2016).

The thermographic analysis is difficult to use in feathered animals because feathers are thermal insulators that block most of the heat emissions (Ferreira et al., 2011). However, the thermography has been applied in the study of thermal comfort of the birds with success.

The use of thermographic imaging technology allows a direct knowledge of the distribution of the surface temperature of the birds in the environment where they are created (Camerini et al., 2016), also allowing the estimation and analysis of heat dissipation (Nascimento et al., 2014).

The influence of environmental factors needs to be understood because even a small effect on infrared temperature may introduce sufficient error to alter research results when used as an alternative assessment tool or it may result in the false interpretation of an animal's state of health, and may lead diagnostically to either false positive or false negative errors (Church et al., 2014).

The purpose of this study aims to evaluate the influence of different air temperatures on the surface temperature of Japanese laying quails by thermographic analysis.

MATERIALS AND METHODS

This research was approved by the Committee on Ethics in the Use of Animals (Protocol 005-2012). Two experiments, of 21 days each, were conducted in four wind tunnels installed in an experimental laboratory applied to small animals. The laboratory was equipped with two air conditioning systems for the maintenance of the variables, air temperature (t_{air}), and relative humidity (RH), below the desired values (setpoints). They were recorded every minute.

The wind tunnels (0.8 x 5.0 m), built in steel sheets and (Polyvinyl chloride) PVC pipes, had partial air recirculation. Each tunnel had two electric heaters and two humidifiers, distributed in two stages of operation, for the most accurate control of the desired air temperature (t_{air}) and RH. Air velocity was manually controlled through potentiometers connected to exhaust fans of 0.40 m in diameter. The thermal acquisition and control system was composed of a data logger (CR1000, Campbell Scientific®), a channel multiplexer (AM16/32B, Campbell Scientific®), a relay controller (SDM-CD16AC, Campbell Scientific®) and air temperature and RH sensors (HMP45C, Vaisala®).

Twenty-eight Japanese quail (*Coturnix coturnix japonica*) were in each experiment. The birds used had the same age, 11 weeks (the beginning of peak production). The birds were selected according to body mass and egg production, to obtain a homogeneous batch and reduce possible individual effects. After the selection, the birds were housed inside the wind tunnels, where they went through an acclimatization period of ten days in t_{air} of 20 °C.

Each tunnel contained two cages (0.50 m long, 0.38 m wide and 0.21 m high, each) with a capacity of 16 birds each, and eight birds housed per compartment, obtaining 118.75 cm² bird⁻¹. Four incandescent bulbs (20 W) were installed inside each tunnel providing illuminance of 20 lux. A light program of 16 hours per day was developed (Molino et al., 2015).

Throughout the experimental period, the birds were submitted to the same feeding intake. Feeding was given *ad libitum* and feeding was carried out four times a day (7 a.m., 11 a.m., 3 p.m. and 7 p.m.). The birds were fed with a balanced diet according to (Rostagno et al., 2011).

The water was kept in a tank external to the tunnels and supplied *ad libitum* throughout the experimental period. Cage cleaning was performed daily at 7 o'clock. The experimental treatments were as follows: 20 °C (control treatment), 22 °C, 24 °C, 26 °C, 28 °C, 30 °C and 32 °C. The control treatment was repeated in each experiment. The assessed values of t_{air} were obtained from the comfort values established by Oliveira

(2004). The RH for all treatments was maintained close to 60%, according to the recommendations of Nääs (1989) and air velocity at $0.3 \pm 0.1 \text{ m s}^{-1}$. In the first experiment of 21 days, the quails were submitted to continuous t_{air} at 20 °C, 22 °C, 24 °C and 26 °C and in the second experiment at 20 °C, 28 °C, 30 °C and 32 °C. Thermographic images of each repetition were shot weekly at 9 a.m. through a Fluke Ti55camera and analyzed using SmartView[®] software (Fig. 1).

The quail areas within each repetition were delimited, excluding the regions belonging to the cage to identify the maximum, average and minimum surface temperatures (ST_{max} , ST_{average} and ST_{min}) later.

The design was completely randomized, with the experiments and evaluated separately with four treatments and four replications each (eight Japanese quails per replication). The variables were submitted to analysis of variance in the statistical program SISVAR 5.3 and the averages were compared through Scott Knott test at a significance of 5%.

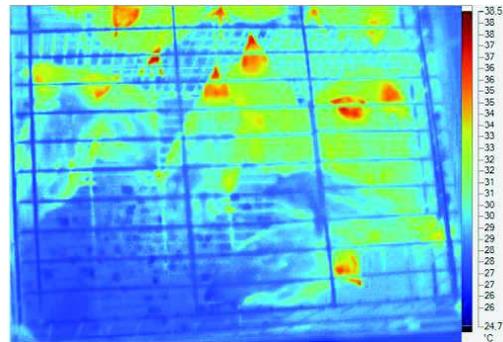


Figure 1. Thermographic image of Japanese quails inside the wind tunnel.

RESULTS AND DISCUSSION

The observed t_{air} levels were close to those desired, with a low standard deviation in both experiments (Table 1). The control treatments registered the highest standard deviations for the observed t_{air} . However, these temperatures remained between 18 °C and 22 °C, considered to be thermal comfort for Japanese quails, according to Oliveira (2004).

Table 1. Maximum, average, and minimum surface temperatures (respectively) of Japanese laying quails submitted to different air temperatures

Thermal variables	Treatments			
Experiment 1				
$t_{\text{airdesired}}$ (°C)	20	22	24	26
$t_{\text{airobserved}}$ (°C)	20.8 ± 0.5	22.2 ± 0.2	24.2 ± 0.2	26.1 ± 0.2
RH _{obs} (%)	60 ± 2	60 ± 2	60 ± 0	60 ± 1
Experiment 2				
$t_{\text{airdesired}}$ (°C)	20	28	30	32
$t_{\text{airobserved}}$ (°C)	21.3 ± 0.6	28.0 ± 0.3	29.9 ± 0.2	31.9 ± 0.3
RH _{obs} (%)	$60,7 \pm 3$	59 ± 2	60 ± 3	60 ± 1

* – $t_{\text{airobserved}}$ e $t_{\text{airdesired}}$: desired and observed air temperatures inside the heated wind tunnels; RH_{obs}: air humidity observed inside the wind tunnels, where the desired value was 60%.

Average values were recorded for the RH close to the desired ones, however in Experiment 2, higher standard deviations were observed in relation to the first one (Table 1) and they were also higher when compared to the deviations of the temperatures.

It was observed that greater deviations of the RH, compared to the deviations of the t_{air} (°C), are explained by the nature of the variable, by the precision of sensors and by the behavior of birds under conditions of heat stress. The dissipation system of heat has been characterized by hyperventilation, by evaporation of water from the lungs of birds under high air temperature (°C) (Carvalho & Fernandes, 2013) and by the evaporation of feces moisture.

Animal behavior is an important means of adapting to the physical and social environment. Based on genetically predisposed patterns, this complex instrument allows rapid reactions towards environmental and internal stimuli with high response plasticity. Different from the hair coat in mammals, birds can use their feather cover in a more flexible way. Due to the connecting net of fine muscles, rather controlled movements of groups of feathers can be exerted. Behavioural patterns play an important role as they allow modifying morphologically preformed thermal windows (Gerken et al., 2006). This type of behavior reduces thermal insulation and increases the skin's contact surface with air, helping to dissipate heat.

For Experiment 1, significant difference was observed among surface temperatures and feed intake as the ambient temperature increased. For Experiment 2, it was observed that the surface temperatures of the quails behaved similarly from 28 °C on (Table 2) and only the control treatment differed from the others by the Scott Knott test ($p < 0.05$).

The surface temperature (ST) is directly related to the t_{air} Sá Filho et al. (2011), because for the dissipation of the body heat to the environment it is necessary that there are temperature differences between them. The higher is the t_{air} , the lower is the heat dissipation in the sensitive form. From 28 °C, the thermal changes in the sensitive form decrease, so these birds have to change heat in the latent form.

Between the t_{air} of 20 °C and 22 °C, it was observed that the ST_{max} , $ST_{average}$ and ST_{min} showed no significant difference between them (Experiment 1, Table 2).

For ST_{max} , it was observed that air temperature 24 °C and 26 °C were the same in the first experiment by the Scott Knott test ($p < 0.05$). The $ST_{average}$ and ST_{min} recorded for the same experiment had differences between air temperature 22 °C, 24 °C and 26 °C.

Table 2. Maximum, average, and minimum surface temperatures (respectively)

Surface temperature			
Experiment 1			
t_{air} (°C)	ST_{max} (°C)	$ST_{average}$ (°C)	ST_{min} (°C)
20	31.9 a	27.1 a	24.2 a
22	32.2 a	28.1 a	25.0 a
24	33.1 b	29.2 b	26.1 b
26	34.0 b	30.2 c	27.7 c
CV	2.58	1.96	2.19
Experiment 2			
20	30.3 a	27.7 a	25.4 a
28	33.0 b	30.6 b	28.6 b
30	33.6 b	30.5 b	28.4 b
32	33.5 b	31.0 b	29.0 b
CV	2.23	2.01	2.14

* – Averages followed by different letters in the column differ from each other by the Scott Knott test ($p < 0.05$).

From the thermographic images, it was possible to observe that the head and feet had higher temperatures. In addition to these regions/parts, in areas with no feathers due to pecking, high surface temperatures were also observed.

The high ST found in the head and foot, according to Shinder (2007) is a genetic characteristic of birds, which have conservative regions/parts in the body, such as feathered and non-conservative regions/parts of heat such as paws, ridge, and dewlap. Burns et al. (2013) found in this species the legs take on a more prominent role in thermal balance than in other species.

Khalil et al. (2012) used infrared thermography to evaluate the adaptive reactions to short-term thermal stress (30 minutes at 35 °C) in different ages, taking as standard the leg temperature of Japanese quails. The authors concluded that increasing environmental temperature during early age will result in thermal conditioning, which can lead to increasing heat tolerance in heat stressed groups.

According to Souza Jr. et al. (2013) in the body regions/parts lacking in feathers, the thermal flow is controlled and modified altering the blood flow. These regions/parts are widely referred to as thermal windows. This term is often applied to any body surface partially or totally involved in thermal changes. They include appendages and areas with few hairs (mammals) or feathers (birds). Therefore, the measured temperatures of several regions/parts, such as the face, wattle, comb, legs, beak and unfeathered areas below the wings radiate directly, will be those on the surface (Yahav & Giloh, 2012).

This type of analysis may also indicate aggressive behavior in adult laying hens housed in cages, since feather pecking is a stress behavior and results in exposure of the skin surface, especially on the backs of birds. According to Sena et al. (2019), when the temperature increases, there is a greater flow of heat towards vasodilated extremities of birds like comb, wattle and feet, in order to exchange heat with the environment and maintain homeothermy.

According to Menuam & Richards (1975), the elevation of air temperature causes higher temperatures in the cloacal, of the epidermis, paw and temperature of the exhaled air by birds, being these artifacts to maintain homeothermy.

Pichová et al. (2017) demonstrated that infrared temperature (IRT) is an objective and feasible method for the feather cover assessment of laying hens kept in different housing systems. However, the commercial use of IRT requires further standardization/development of the methodology to obtain consistent data.

However, hens with less feather coverage could benefit from the additional heat dissipation during hot weather. The differences in sensible heat loss caused by different feather coverage remain validated by more accurate techniques such as calorimetry (Zhao et al., 2013).

CONCLUSIONS

Through thermography, it was possible to determine that air temperatures above 22 °C promote an increase in the maximum, average and minimum surface temperatures of Japanese quails and the highest surface temperatures are found in the head and feet. These areas can be used as standard for the evaluation of the surface temperature of Japanese quails. In addition, this tool can also indicate stress behaviors by identifying other non-feathered areas, which is a feature of feather pecking.

REFERENCES

- Abreu, L.H.P., Yanagi Junior, T., Campos, A.T. & Bahuti, M. 2017. Cloacal and superficial temperatures of broilers subjected to thermal stress. *Engenharia Agrícola* **37**, 877–886.
- Brazilian geography production statistics, IBGE 2017.
http://ftp.ibge.gov.br/Producao_Pecuaria/Fasciculo_Indicadores_IBGE Accessed 10.4.2018 (in Portuguese).
- Burness, G., Huard, J.R., Malcolm, E. & Tattersall, G.J. 2013. Post-hatch heat warms adult beaks: irreversible physiological plasticity in Japanese quail. *Proceedings of the Royal Society B* **280**, 20131436.
- Camerini, N.L., Silva, R.C., Nascimento, J.W.B., Oliveira, D.L. & Souza, B.B. 2016. Surface temperature variation of laying hens created in two creation systems using thermography. *Agropecuária Científica no Semiárido* **12**, 145–152 (In Portuguese).
- Cândido, M.G.L., Tinôco, I.F.F., Pinto, F.A.C., SANTOS, N.T. & Roberti, R.P. 2016. Determination of thermal comfort zone for early-stage broilers. *Engenharia Agrícola* **36** 760–767.
- Carvalho, C.C.S., Souza, C.F., Tinoco, I.F.F., Vieira, M.F.A. & Minete, L.J. 2011. Safety, health and ergonomics of workers in sheds of broilers equipped with different feed systems. *Engenharia Agrícola* **31**, 438–447.
- Carvalho, L.S.S. & Fernandes, E.A. 2013. Formation and quality of egg shells of commercial breeding and laying hens. *Medicina Veterinária* **7**, 35–44 (In Portuguese).
- Cassuce, D.C., Tinôco, I.D.F., Baêta, F.C., Zolnier, S., Cecon, P.R. & Viera, M.D.F. 2013. Thermal comfort temperature update for broiler chickens up to 21 days of age. *Engenharia Agrícola* **33**, 28–36.
- Castilho, V.A.R., Garcia, R.G., Lima, N.D.S., Nunes, K.C., Caldara, F.R., Nääs, I.A., Barreto, B. & Jacob, F.G. Welfare of laying hens in different densities of housing. 2015. *Brazilian Journal of Biosystems Engineering* **9**, 122–131 (In Portuguese).
- Church, J.S, Hegadoren, P.R., Paetkau, M.J., Miller, C.C., Regev-Shoshani, G., Schaefer, A.L. & Schwartzkopf, K.S. 2014. Influence of environmental factors on infrared eye temperature measurements in cattle. *Research in Veterinary Science* **96**, 220–226.
- Ferreira, R.A. 2016. *The greater production with better environment for poultry, pigs and cattle*. 3 Ed. Viçosa Learn easy. 401 pp. (In Portuguese).
- Ferreira, V.M.O.S., Francisco, N.S., Belloni, M., Aguirre, G.M.Z., Caldara, F.R., NÄÄS, I.A., Garcia, R.G., Almeida Paz, I.C.L. & Polycarp, G.V. 2011. Infrared temography applied to the evaluation of metabolic heat loss of chicks fed with different energy doses. *Brazilian Journal of Poultry Science* **13**, 113–118 (In Portuguese).
- Gerken, M., Afnan, R. & Dörl, J. 2006. Adaptative behaviour in chickens in relation to thermoregulation. *Archiv für Geflügelkunde* **70**, 199–207.
- Khalil, H.A., Gerken, M., Hassanein, A.M. & Mady, M.E. 2012. Behavioural responses of two Japanese quail lines differing in body weight to heat stress. *Egyptian Journal o Animal Production* **47 Suppl.**, 151–158.
- Mashaly, M.M., Hendricks, G.L., Kalama, M.A., Gehad, A.E., Abbas, A.O. & Patterson, P.H. 2004. Effect of heat stress on production parameters and immune responses of commercial laying hens. *Poultry Science* **83**, 889–894.
- Menuam, B. & Richards, S.A. 1975. Observations on the sites of respiratory evaporation in the fowl during thermal panting. *Respiration Physiology* **25**, 39–52.
- McManus, C., Tanure, C.B, Peripolli, V., Seixas, L., Fischer, V., Gabbi, A.M., Menegassi, S.R.O., Stumpf, M.T., Kolling, G., Dias, E. & Costa Jr, J.B.G. 2016. Infrared thermography in animal production: An overview. 2016. *Computers and Electronics in Agriculture* **123**, 10–16.
- Molino, A.B., Garcia, E.A., Santos, G.C., Vieira Filho, J.A., Baldo, G.A.A. & Almeida Paz, I.C.L. 2015. Photostimulation of Japanese quail. *Poultry Science* **94**, 156–161.

- Naas, I.A. 1989. *Principles of thermal comfort in the production animal*. 1 ed. São Paulo: Icon Editora Ltda., 183 pp. (in Portuguese).
- Nascimento, G.R., Nääs, I.A., Barracho, M.S., Pereira, D.F. & Neves, D.P. 2014. Infrared thermography in estimating thermal comfort of broiler chickens. *Brazilian Journal of Agricultural and Environmental Engineering* **18**, 658–663 (in Portuguese).
- Nascimento, G.R., Nääs, I.A., Pereira, D.F., Barracho, M.S. & Garcia, R. 2011. Assessment of broilers surface temperature variation when exposed to different air temperature. *Brazilian Journal of Poultry Science* **13**, 259–26.
- Oliveira, B.L. 2004. Importance of management in the production of eggs of quails. In International 2nd Symposium of coturnicultura and 1st Brazilian Congresso of Quail Farming 2004, Lavras. In. Lavras: UFLA, 91 pp. (in Portuguese).
- Pichová, K., Bilčík, B. & Kost'ál, L'. 2017. Assessment of the effect of housing on feather damage in Laying hens using IR thermography. *Animal* **11**, 661–669.
- Pulido-Rodríguez, L.F., Titto, E.A.L., Henrique, F.L., Longo, A.L., Hooper, H.B., Pereira, T.L., Pereira, A.M.F. & Titto, C.G. 2017. Infrared thermography of the ocular surface as stress indicator for piglets postweaning. *Pesquisa Veterinária Brasileira* **37**, 453–458 (in Portuguese).
- Rostagno, H.S., Albino, L. F.T., Donzele, J.L., Gomes, P.C., Oliveira, R.F., Lopes, D.C., Ferreira, A.S. & Barreto, S.L.T. 2011. Nutritional requirements of Japanese quails. In Rostagno, H.S. (Ed). *Brazilian Tables for Poultry and Pigs - Food Composition and Nutritional Requirements*. Viçosa, MG: Federal University of Viçosa, 157–166 pp. (in Portuguese).
- Sá Filho, G.F., Torquato, J.L., Souza Junior, J.B.F., Sundays, H.G.T. & Costa, L.L.M. 2011. Body temperature of quail (*Coturnix coturnix japonica*) submitted to different air temperatures. In X Congress of Ecology of Brazil. (in Portuguese).
- Santana, M.H.M., Hail, E.P, Costa, F.G.P., Figueiredo Jr. Albuquerque, A.M. & Alves, A.R. 2018. Adjust the levels of energy and protein and its relations to laying hens in different thermal conditions. *Pubvet* **12**, 1–12 (in Portuguese).
- Sena, T.L., Bastos-leite, S.C., Vasconcelos, A.M., Goulart, C.C, Farias, M.R.S. & Maranguape, J.S. 2019. Physiological parameters and thermal comfort indices of layers fed vegetable glycerin. *The Journal of Animal & Plant Sciences* **29**, 33–40.
- Shinder, D., Rusal, M., Tanny, J., Druyan, S. & Yahav, S. 2007. Thermoregulatory responses of chicks (*Gallus domesticus*) to low ambient temperatures at an early age. *Poultry Science* **86**, 2200–2209.
- Silva, L.F., Menegali, I., Rippel, D.N., Silva, E.P.F. & Ferreira, F. 2017. Bioclimatic indexes in laying poultry on the different productive phases. *Caderno de Ciências Agrárias* **9**, 31–37 (in Portuguese).
- Souza Jr., J.B.F., Queiroz, J.P.A.F., Sundays, H.G.T., Torquato, J.L., Sá Filho, G.F. & Costa, L.L.M. 2013. Thermographic assessment of japanese quails (*Coturnix coturnix japonica*). *Journal of Animal Behavior and Biometeorology* **1**, 51–64 (in Portuguese).
- Roberto, J.V.B. & Souza, B.B. 2014. Use of infrared thermography in veterinary medicine and animal production. *Journal of Animal Behavior and Biometeorology* **2**, 73–84 (in Portuguese).
- Yahav, S. & Giloh, M. 2012. Infrared Thermography – Applications in Poultry Biological Research. In *Infrared Thermography*. 1Ed. 93–116.
- Yahav, S., Straschnow, A., Luger, D., Shinder, D., Tanny, J. & Cohen, S. 2004. Ventilation, sensible heat loss, broiler energy, and water balance under harsh environmental conditions. *Poultry Science* **83**, 253–258.
- Zhao, Y., Xin, H. & Dong, B. 2013. Use of infrared thermography to assess laying-hen feather coverage. *Poultry Science* **92**, 295–302.