Sensible and latent heat flow of Japanese quails kept in different thermal environments

Joab Jorge Leite de Matos Júnior
UFCG: Universidade Federal de Campina Grande
Dermeval Araújo Furtado
UFCG: Universidade Federal de Campina Grande
Neila Lidiany Ribeiro (neilalr@hotmail.com)
Instituto Nacional do Semiarido https://orcid.org/0000-0002-6410-244X
Jordânio Inácio Marques
UFMA: Universidade Federal do Maranhao
Patrício Gomes Leite
UFMA: Universidade Federal do Maranhao
José Wallace Barbosa do Nascimento
UFCG: Universidade Federal de Campina Grande
Valéria Pereira Rodrigues
UFCG: Universidade Federal de Campina Grande
José Pinheiro Lopes Neto
UFCG: Universidade Federal de Campina Grande
Ladyanne Raia Rodrigues
UFCG: Universidade Federal de Campina Grande
Severino Guilherme Caetano Gonçalves dos Santos
INSA

Research Article

Keywords: cloaca, convection, physiological parameters, radiation

Posted Date: February 23rd, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1347121/v1

Sensible and latent heat flow of Japanese quails kept in different thermal environments

Joab Jorge Leite de Matos Júnior[1], Dermeval Araújo Furtado[2], Neila Lidiany Ribeiro[3], Jordânio Inácio Marques[4], Patrício Gomes Leite[4], José Wallace Barbosa do Nascimento[2], Valéria Pereira Rodrigues[1], José Pinheiro Lopes Neto [2], Ladyanne Raia Rodrigues[1], Severino Guilherme Caetano Gonçalves dos Santos[3]

[1]Doutor (a) em Engenharia Agrícola, Universidade Federal de Campina Grande-Paraíba- Brasil

[2]Professor Titular da Unidade Acadêmica de Engenharia Agrícola, Universidade Federal de Campina Grande, Centro de Tecnologia e Recursos Naturais, Campina Grande – Paraíba

[3]Bolsista PCI/CNPq Instituto Nacional do Semiárido, Campina Grande, Paraíba, Brasil

[4]Professor Substituto da Universidade Federal do Maranhão

----

*Corresponding author. Tel.: +55 83998172665

E-mail addresses: neilalr@hotmail.com

Abstract: The aim of this study was to estimate the heat flux through sensitive mechanisms and respiratory evaporation of Japanese quails kept in thermoneutral and warm environments, using simple environmental and physiological measures. 192 nine-week-old quails were used, distributed in a completely randomized design at two temperatures (T1 = 24 °C and T2 = 32 °C), with 12 replicates of eight birds each, with an experimental period of 63 days, divided into three 21-day periods. Physiological measurements of respiratory rate (RR), cloacal temperature (TC) and body surface temperature (TS) were measured twice a week. The behavior of the energy balance in the climatic chambers was obtained using the total thermal energy exchanges per unit surface area of the birds, derived from the sum of sensible (radiation and convection) and latent heat exchanges. Respiratory rate ($P<.0001$), surface temperature ($P<.0001$) and cloacal temperature ($P=0.0047$) were higher in the 32 °C environment. The expired air temperature ($P<.0001$) and heat loss by respiratory evaporation ($P<.0001$) showed higher values when the quails were in an environment of 32 °C, while the heat losses by convection ($P<.0001$) and radiation ($P<.0001$) were higher in a thermal comfort environment. In Japanese quails kept in a controlled environment, sensible heat dissipation by convection is the main way to eliminate excess thermal energy, when the air temperature is up to 32 ºC.

Keywords: cloaca, convection, physiological parameters, radiation

Introduction

Quails breeding is an expanding activity in tropical regions, which are characterized by strong insolation, high air temperatures of up to 40 ºC (Souza et al., 2014) and sparse and irregular rainfall (Abdelsattar et al., 2020). The Japanese quails is a bird adapted to hot climates, with small size, earliness, productivity, requiring small spaces for production and little labor (Guimarães et al., 2014; Khalilipour et al., 2019). In quails farming, optimal productivity is achieved when the animals are subjected to an environmental condition that favors minimal energy exchanges to maintain thermal balance (Nascimento et al., 2014).

The thermoneutral zone for quails in the initial phase is between 35 and 38 °C and in the laying phase between 18 and 22 °C (Murakami & Ariki, 1998). However, in birds in the thermoneutral zone, little energy is dissipated to maintain their homeothermy. Cloacal temperature is considered a measure that represents the body core temperature and can be used as a good indicator of the animals' comfort or thermal stress condition (Brown-Brandl et al., 2003). Quails plumage plays a fundamental role in the thermal balance between the organism and the environment, so they directly interfere in the efficiency of heat elimination mechanisms (Malheiros et al., 2000).

Sensible exchange, which can be by conduction, convection and radiation, has great prominence in thermal balance, however, this heat exchange mechanism directly depends on a temperature differential (thermal gradient) between the average surface temperature and the ambient temperature (Moura et al., 2016); consequently, the greater this difference, the more efficient the thermal exchanges will be. According to Brown-Brandl et al. (1997), the greater the temperature differential, the more efficient the heat exchange through the sensible means. Another form of heat exchange is latent exchanges, mainly evaporation, reflected in the bird as a form of panting (Silva, 2008).

The aim of this study was to estimate the heat flux through sensible mechanisms and respiratory evaporation of Japanese quails kept in thermoneutral and warm environments, using simple environmental and physiological measures.

Material and methods

Ethics Committee and Experimental Site

All procedures used were approved by the Animal Use Ethics Committee of the Federal University of Campina Grande (Protocol No. 089.2017).

The experiment was carried out in Campina Grande, Paraíba, Brazil (7°13'11"S; 35º53'31"W and 547 m altitude). According to Köppen’s climate classification, the region's climate is classified as tropical, with wet and dry seasons (AS'), with maximum annual temperature of 32 ºC and minimum of 17 °C, and average annual precipitation of 765 mm.

Climatic chambers

The experiment was carried out in two climatic chambers, with dimensions of 3.07 m x 2.77 m x 2.6 m, in length, width and height, respectively (Figure 1), located in the Laboratory of Rural Constructions and Ambience, of the Academic Unit of Agricultural Engineering, Federal University of Campina Grande, PB.

For environmental control, the chambers are equipped with: electric resistance air heater; hot/cold split air conditioning, Samsung brand, AS18UWBUXXAZ model, with power of 1750 W, and cooling capacity of 18,000 BTU/h, flow rate of 828 m^3/h; and Britânia brand air humidifier, BUD04B model, with capacity of 4.5 L and a mist flow (average value) of 300 ml h^{-1}. The relative humidity of the air was controlled by air humidifiers and measured by sensors. Ventilation was provided through the use of side fans and exhausts; these were installed at the height of the geometric center of the birds. Wind speed was measured at five different points, with the aid of a digital thermohygroluximeter anemometer (model LM-8000 AKSO® brand with measuring range: 0.4 to 30.0 m/s and accuracy: ± 3%). The chambers have temperature and humidity sensors, and environmental data were collected and recorded every 15 min by sensors (Full Gauge SB-56) coupled to the data acquisition system, through an MT-530 PLUS type controller from Full Gauge Controls®, controlled via computer through SITRAD® (software for acquisition, control, monitoring and visualization of data in climate chambers).

Animals and Experimental Arrangement

192 quails with nine weeks of age were distributed in a completely randomized design at two temperatures (T1 = 24 °C and T2 = 32 °C), with 12 replicates of eight birds each, with an experimental period of 63 days, divided into 3 periods of 21 days.

The quails were nine weeks old, with mean weight of 168 ± 5g at the beginning of the experiment (14 weeks old) and 175 ± 5g at the end (24 weeks old), housed in sets of cages in the chambers, each set composed of four floors, three cages per floor, made of galvanized wire, with dimensions of 50 x 33 x 20 cm (width, depth and height, respectively), subjected to a stocking rate of 206 cm^2 $birds^{-1}$, 8 birds per cage. The cages were equipped with zinc foil feeders and individual nipple drinkers.

The birds went through an adaptation period of three weeks, in which the chambers were programmed to keep the quails at a thermal comfort temperature (24 ºC) during the day and at room temperature at night. Egg production was counted and, at the end, the quails were weighed for homogeneous distribution in the experimental units, considering their body weight and average laying rate. After distribution, chamber temperatures were adjusted to 24.0 ± 1.0 ºC within the thermal comfort zone and 32 ± 1.2 ºC above the thermal comfort zone (Castro et al., 2017; Soares et al. al., 2019b). These values were maintained for a period of 12 hours (7:00 to 19:00) and the chamber doors were opened from 19:01 to 6:59 at room temperature (22 ± 2.0 ºC), simulating the environmental conditions of the semiarid region. The relative humidity of the air in the chambers during the experimental period was 65.0±5.0% and the mean wind speed was 0.6±0.5 m s^{-1}. The daily light program adopted was 17 hours of light and 7 hours of darkness, using 20W and 220V fluorescent lamps.

Feed management

During the experimental period, the birds were subjected to identical feeding management, consuming corn and soybean meal-based food for laying quails (Table 1). The nutritional composition of the ingredients used was obtained based on the tables by Rostagno et al. (2011). Water and feed were provided *ad libitum*. Leftovers and residues were weighed and deducted from the amount of feed weighed initially to calculate the feed and water consumption of the birds.

Physiological variables

Respiratory rate (RR), cloacal temperature (TC) and body surface temperature (TS) were measured twice a week, at two times (morning and afternoon), with the birds kept inside the climatic chamber, two hours after feeding to avoid interference from the caloric increase; for this, two birds from each plot were marked and identified beforehand.

The respiratory rate (mov min^{-1}) was obtained through visual assessment, considering the number of times the birds inhaled air for 20 seconds, and then the value obtained was multiplied by three; cloacal temperature (°C), determined using a digital veterinary clinical thermometer, inserted about 2 cm into the cloaca of the birds for, on average, 2 minutes or until the temperature stabilized; for surface and mean temperatures (TSM), an infrared thermometer model ITTI – 380, Instrutherm brand with laser sight (-10 to 50 °C), with an accuracy of ± 2%, was used to measure the temperature of the head, wing, foot and back (moving the feathers away from the collection site to measure directly on the skin), at a distance of 10 cm between the animal and the equipment, calculating the average surface temperature - eq. (1), according to the equation proposed by Nascimento et al. (2013):

TSM = (0.03*Head Temp)+(0.70*Trunk Temp)+(0.12*Wing Temp) + (0.15*Foot Temp) (Eq. 1)

Thermal exchanges

The behavior of the energy balance in the climatic chambers was obtained using the total thermal energy exchanges per unit surface area of the birds, derived from the sum of sensible (radiation and convection) and latent heat exchanges. Sensible heat exchange between the surrounding environment and the birds, per unit of body surface area, was determined using the model by Turnpenny et al. (2000):

$$G_s = C_R + L \quad \text{(Eq. 3).}$$

Where,

Gs - sensible heat exchange between the bird and the environment (W/m^2); CR - convection heat flux (W/m^2); L - radiant heat flux (W/m^2).

Conduction exchanges were not included in Equation 3 as they are considered negligible. The convection heat flux, CR, was determined by Equation 4, proposed by McArthur (1987).

$$C_R = \frac{\rho * C_p}{rh} * (T_s - T_a) \quad \text{(Eq. 4).}$$

Where,

CR - convection heat flux (W/m^2);

ρ - air density (kg/m^3);

Cp - specific heat of air (J/kg °C);

rh - resistance of the boundary layer to convection heat transfer (m^2 K/W);

Ts - body surface temperature (K);

Ta - air temperature (K).

The resistance of the boundary layer to convection heat transfer can be calculated by Equation 5.

$$rh = \frac{\rho * C_p * d_b}{k * Nu} \quad \text{(Eq. 5).}$$

Where,

rh - resistance of the boundary layer to convection heat transfer (m^2 K/W);

ρ - air density (kg/m^3);

Cp - specific heat of air (J/kg °C);

db - average diameter of the bird's body (m);

k - thermal conductivity of air (W/m K);

Nu - Nusselt's number.

The average diameter of birds, for each study period, was estimated by Equation 6, proposed by Mitchell (1930).

$$d_b = 0.131 * P^{0.33} \quad \text{(Eq. 6)}$$

Where,

db - average body diameter of birds (cm);

P – average weight of birds (g).

The Nusselt number was determined by Equation 7, considering the representation of the bird's body as a sphere.

$$Nu = 2 + 0.4 * R_e^{1/2} + R_e^{2/3} P_r^{0.4} \quad \text{(Eq. 7)}$$

Where,

Nu - Nusselt's number;

Re - Reynolds number.

The Reynolds number was obtained by Equation 8.

$$R_e = \frac{V * d_t}{v} \quad \text{(Eq. 8)}$$

Where,

Re - Reynolds number.

Ʋ - kinematic air viscosity (m^2/s);

dt - diameter of the black globe (m);

V – average air displacement velocity (m/s).

The exchanges for longwave radiation were calculated using Equation 9, proposed by McArthur (1987), considering only longwave radiation, as there is no incidence of solar radiation inside the chamber.

$$L = \frac{\rho * C_p}{R_r} * (T_s - \overline{T}_r) \quad \text{(Eq. 9)}$$

Where,

L - radiant heat flux (W/m²);

ρ - air density (kg/m^3);

Cp - specific heat of air (J/kg ºC);

Rr - resistance of the boundary layer to heat transfer by radiation (m² K/W);

Ts - body surface temperature (K);

Tr - average radiant temperature (K).

The resistance of the boundary layer to heat transfer by radiation was calculated by:

$$R_r = \rho * C_p * (4 * \varepsilon_s * \sigma * \overline{T}_M^3)^{-1} \quad \text{(Eq. 10)}$$

Where,

Rr - resistance of the boundary layer to heat transfer by radiation (m^2 K/W);

ρ - air density (kg/m^3);

Cp - specific heat of air (J/kg °C);

ƐS - emissivity (0.94);

σ - Stefan-Boltzmann constant ($5.67051*10^{-8}$, W/m^2K^4);

T_M - Average temperature between Ts and (K).

The mean radiant temperature was obtained by Equation 11, proposed by Silva (2001).

$$\overline{T}_r = \left[\frac{1.053 * h_c}{\sigma} * \left(T_g - T_a\right) + T_g^4\right]^{0.25} \quad \text{(Eq. 11)}$$

Where,

hc - globe convection coefficient;

Tg - black globe temperature (K).

The globe's convection coefficient was calculated by Equation 12

$$h_c = 0.38 * k * d * R_e^{0.6} * P_r^{\frac{1}{3}} \quad \text{(Eq. 12)}$$

Where,

k - thermal conductivity of air (W/m K);

Pr - Prandtl's number, dimensionless.

Prandtl's number was obtained by Equation 13.

$$P_r = \frac{\rho * C_p * v}{k} \quad \text{(Eq. 13)}$$

Latent exchanges were defined as the process of energy loss through the respiratory tract. To quantify the exchanges of thermal energy in latent form, the empirical relationship of Hellickson & Walker (1983) was used, determined by Equation 14, considering the climatic chamber as a thermodynamic system, where mass and energy cross the boundary.

$$E = \rho * V * (W_{ex} - W_a) * \lambda_s \quad \text{(Eq. 14)}$$

Where,

E - total heat flux by evaporation (W/m²);

ρ – air density (kg/m^3);

V – air velocity (m/s);

Wex – partial vapor pressure of the exhaust air (kg/kg of dry air);

Wa – partial vapor pressure of the inlet air (kg/kg of dry air);

λ – latent heat of vaporization of water at the same temperature as the air on the surface of the respiratory tract, 2402 kJ/kg according to With (1996).

The partial vapor pressure of water (ea) was calculated by the product between the saturation vapor pressure (es) and the relative humidity of the air (RH) according to Equation 15.

$$e_a = \frac{es * RH}{100} \quad \text{Eq. 15}$$

Where,

ea – partial vapor pressure of water (kPa);

es - saturation vapor pressure (kPa);

RH – relative humidity (%).

The saturation vapor pressure of water was calculated using the Tetens:

$$e_s = 0.6108 * 10^{\frac{7.5 * T_a}{237.3 + T_a}} \quad \text{(Eq. 16)}$$

Where,

es - saturation vapor pressure of water (kPa);

Ta – air temperature.

The physical characteristics of the air were estimated using mathematical models, as a function of each air temperature evaluated, as suggested by Silva (2000) (Table 2).

Statistical analysis

The means were compared by the Student test at 5% probability using the General Linear Model (GLM) procedure of SAS (Statistical Analysis System, version 9.2). The following mathematical model was used:

Yijk = μ + Zi + Ɛijk, (1) where Yijk is the dependent variable; μ is the overall mean; Zi = is the effect of temperature Z (i = 1,2); and Ɛijk is the random error, considering mean 0 and variance $σ^2$.

Results

Respiratory rate (P<.0001), surface temperature (P<.0001) and cloacal temperature (P=0.0047) were higher in the 32 °C environment (Table 3). The expired air temperature (P<.0001) and heat loss by respiratory evaporation (P<.0001) showed higher values when the quails were in an environment of 32 °C, while the heat losses by convection (P<.0001) and radiation (P<.0001) were higher in a thermal comfort environment (Table 4).

The results show that the sensible heat flux mechanisms contributed in greater proportion to the total heat dissipation, 64.09% and 51.65%, in environments at 24 °C and 32 °C, respectively (Figure 2). However, the heat loss by convection was greater in the thermoneutral environment (24 °C), while the heat flux by radiation showed negligible values in both environments (Table 4).

Discussion

In environments with high temperature, physiological responses are altered, aiming to intensify peripheral circulation and maximize non-evaporative heat loss (Borges et al., 2003). Simultaneously, in an attempt to increase heat dissipation, birds modify their behavior, opening their wings and leaving them away from the body, ruffling their feathers and avoiding grouping (Furlan & Macari, 2002). This combination of physiological and behavioral responses, through the production and release of heat, aims to maintain a normal body temperature (Abu-Dieyeh, 2006).

In this study, the respiratory rate showed an increase of 11.79% in the environment with a temperature of 32 °C compared to the environment of 24 °C. This result is in agreement with those reported by Santos et al. (2014). The literature points out that sudden increases in respiratory rate or for long periods can cause dehydration and reduce the production and quality of quails eggs (Ribeiro et al., 2016, Rodrigues et al., 2016). Under heat stress conditions, increased respiratory rate causes an acid-base imbalance, known as respiratory alkalosis. As a result, most metabolic activities are compromised and while there is no return to homeostatic balance, performance will be impaired, which may result in the bird's death (Borges et al., 2003).

The elevation of the surface temperature of quails in an environment of 32 °C can be explained by the absence of sweat glands and by their body covered with feathers, which may have difficulty in eliminating excess body heat. The animal stimulates heat transmission from the body's core to the periphery, increasing blood flow to peripheral tissues not covered by feathers (feet and facial region) and highly membranous and vascularized body regions, such as crests and barbels, important sites of thermolysis (Camerini et al., 2016; Santos et al., 2019; Souza Junior et al., 2019; Cândido et al., 2020).

In a study carried out with broiler chickens, Dalke et al. (2005) observed an increase in cloacal and surface temperatures (wing, back, head, breast, leg) in broiler chickens at 42 days of age kept in an environment of 32 °C compared to those kept at 22 °C (thermoneutral). Temperature variations on the external surface of birds (head, wing, back, chest and leg) are mechanisms to maintain the constant internal temperature (Dalke et al., 2005; Nascimento, et al., 2014).

Among the measurements used to indicate conditions of comfort or heat stress in birds, there is the cloacal temperature, considered as a representation of the core body temperature (Brown-Brandl et al., 2003). The cloacal temperature of birds can vary with age, weight, sex, physical activity, ingestion and thermal environment. Our findings show that the cloacal temperature of quails increased by 0.29 °C, when the room temperature rose from 24 °C to 32 °C. Although the cloacal temperature showed a statistical difference when comparing the different thermal environments, the quails remained with the cloacal temperature within the normal range [40 to 42 ºC] (Ribeiro et al., 2016; Soares et al., 2019b). Therefore, despite being kept in environments considered above their thermal comfort zone and with an increase in their respiratory rate and surface temperature, the birds maintained their homeothermy, demonstrating adaptability to hot environments (Rodrigues et al., 2016; Silva et al., 2017).

The rise in expired air temperature in the 32 °C environment may be a response to the increases in respiratory rate, body temperature and surface temperature, which are physiological mechanisms used to dissipate excess body heat (Nascimento et al., 2011).

According to Brown-Brandl et al. (1997), the greater the temperature differential, the more efficient the heat exchange through the sensible means. Thus, as can be seen, the heat flux values through the sensible means decreased in line with the decrease in the difference between ambient and bird temperatures, a condition that can be verified by the increase in surface and cloacal temperatures, in the environment at 32°C .

In a study with broiler chickens, Nascimento et al. (2014) found that even 30 minutes of exposure to a stressful condition resulted in a decrease in sensible heat flux, being related to a higher area-to-volume ratio of chicken in the first weeks of life, which leads to greater heat loss from the body surface. Our results followed this trend.

According to Nascimento (2010), when the air temperature is at levels close to 21 °C, the bird can lose up to 75% of heat through the sensible means. However, when the ambient temperature approaches the surface temperature of birds, evaporative mechanisms (mainly respiratory evaporation) assume a more important role in maintaining the thermal balance (Nascimento et al., 2014). Practically, this condition can be observed indirectly with the increase in the respiratory rate of birds.

In the present study, the loss of latent heat by evaporation was greater when the quails were in an environment of 32 °C, contributing with 48.35% of the total heat dissipated in the hot environment. Latent heat flow mechanisms require higher energy expenditure when compared to sensible means. In a hot environment, increased energy demand for thermoregulation can compromise the productive performance, reproductive performance and welfare of birds (Alagawany et al., 2017). Therefore, the ideal is to provide a maximization of sensible losses, thus avoiding energy expenditure due to panting.

Conclusions

In Japanese quails kept in a controlled environment, sensible heat dissipation by convection is the main way to eliminate excess thermal energy, when the air temperature is up to 32 ºC. The results suggest that Japanese quails have a lower sensitivity to heat stress, and this phenomenon is reflected by the participation of sensible and latent heat flux.

Availability of data and material: Not applicable for that section.

Code availability: Not applicable for that section.

Authors' contribution

Joab Jorge Leite de Matos Júnior: Data curation, formal analyses, investigation, writing–original draft

Dermeval A. Furtado: Conceptualization, supervision, funding acquisition, methodology

Neila L. Ribeiro: Formal analyses, methodology, writing–original draft, writing–review

Jordânio Inácio Marques: Data curation, formal analyses, investigation

Patrício Gomes Leite: Data curation, formal analyses, investigation

José W. Barbosa do Nascimento Severino Gonzaga Neto: Supervision, investigation, methodology

Valéria Pereira Rodrigues: Data curation, formal analyses, investigation

José Pinheiro Lopes Neto: Supervision, investigation, methodology

Ladyanne Raia Rodrigues: Data curation, formal analyses, investigation

Severino Guilherme Caetano Gonçalves dos Santos: Data curation, formal analyses, investigation

Funding: The authors wish to thank the Brazilian National Council for Scientific and Technological Development (CNPq)

Declarations

Ethics approval: All procedures used were approved by the Animal Use Ethics Committee of the Federal University of Campina Grande (Protocol No. 089.2017).

Conflict of interest: The authors declare no competing interests.

References

Abdelsattar, M. M., Hussein, A. M. A., Abd El-Ati, M. N., Saleem, A. M. 2020. Impacts of saline water stress on livestock production: A review. International Journal of Agricultural Science, 2, 1-12.

Abu-Dieyeh, Z.H.M. 2006. Effect of high temperature *Per se* on growth performance of broilers. International Journal of Poultry Science, 5, 19-21.

Alagawany, M., Farag, M.R., Abd El-Hack, M.E., Patra, A. 2017. Heat stress: effects on productive and reproductive performance of quail. World's Poultry Science Journal, 73, 747-756.

Borges, S.A., Maiorka, A., Silva, A.V.F. 2003. Fisiologia do estresse calórico e a utilização de eletrólitos em frangos de corte. Ciência Rural, 33, 975-981.

Brown-Brandt, T. M., Yanagi Júnior, T., Xin, H., Gates, R.S., Bucklin, R.A., Ross, G.S. 1997. Physiological responses of tom turkeys to temperature and humidity change with age. Journal of Thermal Biology, 22, 43-52.

Brown-Brandtl, T.M., Xin, H., Bucklin, R.A., Yanagi, T.Jr., Gates, R.S., Ross, G.S. 2003. A new telemetry system for measuring core body temperature in livestock and poultry. Applied Engineering in Agriculture, St. Joseph, 19, 583- 589.

Camerini, N.L., Silva, R.C., Nascimento, J.W.B., Oliveira, D.L., Souza, B.B. 2016. Variação da temperatura superficial de aves poedeiras criadas em dois sistemas de criação utilizando termografia. Agropecuária Científica no Semiárido, 12, 145-152.

Cândido, M.G.L., Tinôco, I.F.F., Albino, L.F.T., Freitas, L.C.S.R., Santos, T.C., Cecon, P.R., Gates, R.S. 2020. Effects of heat stress on pullet cloacal and body temperature. Poultry Science, 99, 2469-2477.

Castro, J.O., Yanangi Junior, T., Ferraz, P.F.P., Fassani, E.J. 2017 Japanese laying quail's behavior under different temperatures. Energia na Agricultura 32:141-147.

Dahlke, F., Gonzales, E., Gadelha, A.C., Maiorka, A., Borges, S.A., Rosa, P.S., Faria Filho, D.E., Furlan, R.L. 2005. Empenamento, níveis hormonais de triiodotironina e tiroxina e temperatura corporal de frangos de corte de diferentes genótipos criados em diferentes condições de temperatura. Ciência Rural, 35, 664-670.

Furlan, R.L., Macari, M. 2002. Termorregulação. In: Macari M, Furlan RL, Gonzales E. Fisiologia aviária aplicada a frangos de corte. 2 ed. Jaboticabal (SP): FUNEP/UNESP.

Guimarães, M.C.C., Furtado, D.A., Nascimento, J.W.B., Tota, L.C.A., Silva, C.M., Lopes, K.B.P. 2014. Effect of season on production performance of quail in the semiarid region of Paraiba state, Brazil. Revista Brasileira de Engenharia Agrícola e Ambiental, 18,231–237.

Hellickson, M.A., Walker, J.N. 1983. Ventilation of Agricultural Structures. St. Joseph: ASABE.

Khalilipour, G., Maheri, N.S., Shadddel, A.T. 2019. Effects of Saline Drinking Water on Growth Performance and Mortality Rate of Japanese Quails (*Coturnix Japonica*). Journal Agricultural National, 22, 942-947.

Malheiros, R.D., Moraes, V.M.B., Bruno, L.D.G., Malheiros, E.B., Furlan, R.L., Macari, M. 2000. Environmental temperature and cloacal and surface temperatures of broilers chicks in first week post hatch. Journal of Applied Poultry Research, 9, 111-117.

McArthur, A.J. 1987. Thermal interaction between animal and microclimate: a comprehensive model. Journal of Theoretical Biology, 126, 203-238.

Mitchell, H. H. 1930. The surface area of single comb white leghorn chickens. The Journal of Nutrition, 2, 443-449.

Moura, P.S., Furtado, D.A., Souza, J.F. 2016. Temperatura superficial e emissão de calor sensível de codornas japonesas mantidas em diferentes temperaturas. Congresso Técnico Científico da Engenharia e da Agronomia – CONTECC.

Murakami, A. E., Ariki, J. 1998. Produção de codornas japonesas. Jaboticabal: FUNEP.

Nascimento, G.R., Nääs, I.A., Pereira, D.F, Baracho, M.S., Garcia, R. 2011. Assessment of Broiler Surface Temperature Variation When Exposed to Different Air Temperatures. Brazilian. Journal of Poultry Science, 13, 259-263.

Nascimento, S.T., Silva, I.J.O. 2010. As perdas de calor das aves: entendendo as trocas de calor com o meio. 2010. Disponível em: http://www.avisite.com.br/cet/ img/20100 916_trocasdecalor.pdf. Acesso em: 20 de novembro de 2021.

Nascimento, S.T., Silva, I.J.O., Maia, A.S.C., Castro, A.C., Vieira, F.M.C. 2014 Mean surface temperature prediction models for broiler chickens—a study of sensible heat flow. International Journal of Biometeorol. 58, 195–201

Ribeiro, T.L.A.; Souza, B.B.; Brandão, P.A.; Roberto, J.V.B.; Medeiros, T.T.B.; Silva, J.J. and Carvalho Júnior, J.E.M. 2016. Different levels of protein and energy on physiological behavior and performance of European quail in the Brazilian semiarid. Journal of Animal Behavior and Biometeorology, 4, 76-83

Rodrigues, L.R., Furtado, D.A., Costa, F.G.P., Nascimento, J.W.B., Cardoso, E. A. 2016. Thermal comfort index, physiological variables and performance of quails fed with protein reduction. Revista Brasileira de Engenharia Agrícola e Ambiental, 20, 378-384.

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., Euclides, R.F. 2011. Brazilian Tables for Poultry and Swine - Composition of Feedstuffs and Nutritional Requirements. 3ª ed. – Viçosa - MG.

Santos, S.M., Tinôco, I.F.F., Barreto, S.L.T., Amaral, A.G., Pires, L.C., Ferreira, A.S. 2014. Determination of upper limits of the thermal comfort zone for quails acclimatized in Brazil 22-35 days old. Revista Brasileira de Saúde e Produção Animal, 15, 350-360.

Santos, T.C., Gates, R.S., Tinôco, I.F.F., Zolnier, S., Baêta, F.C. 2019. Productive performance and surface temperatures of Japanese quail exposed to different environment conditions at start of lay. Poultry Science, 98, 2830-2839.

Sas Institute. 2002. SAS system for Windows. Cary: SAS Institute inc.

Silva, R.G. 2000. Introdução a Bioclimatologia animal. São Paulo: Nobel.

Silva, R.G. 20001. Introdução à Bioclimatologia Animal. São Paulo: Nobel.

Silva, R.G. 2008. Biofísica ambiental – os animais e seu ambiente. Jaboticabal: Funep.

Silva, RC., Nascimento, J.W.B., Rodrigues, L.R., Leite, P.G., Galvão Sobrinho, T., Furtado, D.A. 2017. Quality of quail eggs confined in thermoneutral environment and heat stress. Journal of Animal Behaviour and Biometeorology, 5, 139-143.

Soares, K.O., Saraiva, E.P., Santos, J.D.C., Amorim, R.G. Costa, J.L.G., Veríssimo, T.S., Guerra, R.R., Santos, S.G.C.S. 2019. Effect of ambient temperature on the production parameters and egg quality of Japanese quail (Cortunix japonica). Biological Rhythm Research, 52, 1130-1137.

Sousa, M.S., Tinôco, I.F.F., Barreto, S.L.T., Amaral, A.G., Pires, L.C., Ferreira, A.S. 2014. Determination of upper limits of the thermal comfort zone for quails acclimatized in Brazil 22-35 days old. Revista Brasileira de Saúde e Produção Animal, 15, 50-360.

Souza-Junior, J.B.F., El-Sabrout, K., Arruda, A.M.V., Costa, L.L.M. 2019. Estimating sensible heat loss in laying hens through thermal imaging. Computers and Electronics in Agriculture, 166, 105038.

Turnpenny, J.R., Mcarhtur, A.J., Clark, J.A., Wathes, C.M. 2000. Thermal balance of livestock, 1. A parsimonious model. Agricultural and Forest Meteorology, 101, 15-27

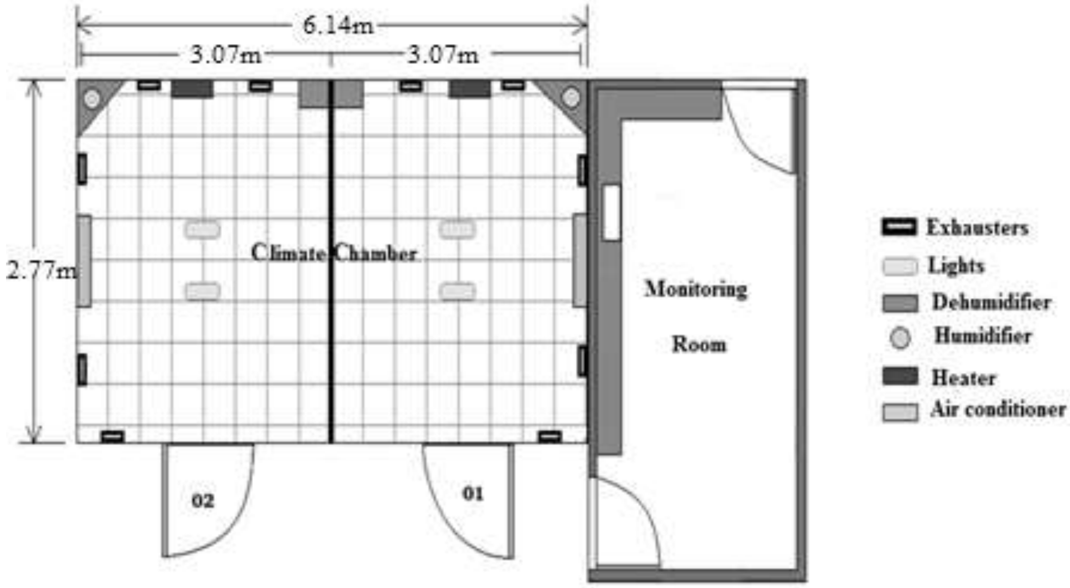

Figure 1. Internal layout of the climate chambers and monitoring room

Table 1. Percentage composition and nutritional profile of the feed

Ingredient	%
Corn Grain 7.88%	57.4
Soybean Meal 45.22%	28.5
Soy oil	4.54
Limestone	7.20
Dicalcium phosphate	1.19
salt	0.32
DL-Methionine	0.41
L-Lysine	0.31
L-Threonine	0.07
Choline chloride	0.07
Mineral Premix	0.05
Posture Vitamin Premix	0.02
Chemical composition	
Metabolizable energy (kcal/kg)	2800
Crude protein (%)	18.00
Methionine + Cysteine (%)	0.88
Lysine (%)	1.08
Threonine (%)	0.65
Calcium (%)	3.09
Available phosphorus (%)	0.32

Mineral Premix per kg of feed: Mn, 60 g; Fe, 80 g; Zn, 50 g; Cu, 10 g; Co, 2 g; I, 1 g; and vehicle q.s.p., 500 g.Vitamin Premix (Concentration/kg): Vit. A - 15,000,000 IU, Vit. D3 - 1,500,000 IU, Vit. E - 15,000 IU, Vit.B1 - 2.0 g, it.B2 - 4.0 g, Vit B6 - 3.0 g, Vit.B12 - 0.015 g, Nicotinic acid - 25 g, Pantothenic acid - 10 g, Vit.K3 - 3.0 g, Folic acid - 1.0 g, Selenium - 250 mg, and vehicle. q.s.p. - 1,000 g. 3 Ethoxyquin – 10g, and q.s.p. – 1,000g.

Table 2. Determination of air characteristics for the different temperatures evaluated (ºC).

Air characteristics	Equations	Units
Kinematic viscosity	$v = 1.32909 * 10^{-5} + 9*10^{-8} * T$	(m^2/s)
Density	$p = 1.289764 - 0.004111 * T$	(kg/m^3)
Thermal conductivity	$k = 0.024324 + 6.2909*10^{-5} * T$	(W/m °C)
Specific heat	$C_p = 1005.524 + 0.033714 * T$	(J/kg °C)

Table 3. Mean and standard deviation of physiological responses of submitted Japanese quails

Response variables	Air temperature		*P-value*
	24 °C	32 °C	
Respiratory rate (mov min^{-1})	24.09±1.47b	27.31±1.89a	<.0001
Surface temperature (°C)	33.52±3.08b	38.34±2.09a	<.0001
Ventilation temperature (°C)	41.56±0.50b	41.85±0.21a	0.0047

Different letters on the line differ from each other by the t test at the 5% probability level

Table 4. Mean and standard deviation of the thermal exchanges of quails submitted to comfort temperature and thermal stress.

Response variable	Air temperature		*P-value*
	24 °C	32 °C	
Expired air temperature, °C	32.80±0.00b	38.70±0.00a	<.0001
Convection heat loss, W m^{-2}	79.33±23.22a	54.61±19.50b	<.0001
Radiation heat loss, W m^{-2}	0.08±0.04a	0.02±0.03b	<.0001
Evaporative heat loss, W m^{-2}	44.50±1.54b	51.13±2.11a	<.0001

Different letters on the line differ from each other by the t-test at the 5% probability level.

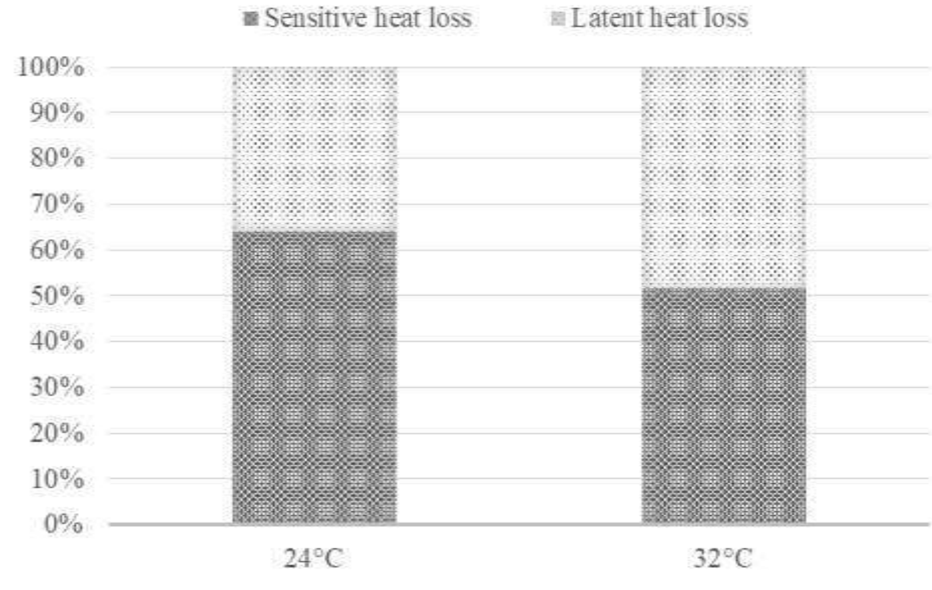

Figure 2. Participation of sensible and latent heat loss in Japanese quails in different thermal environments.