http://dx.doi.org/10.1590/1678-4162-12937

***Arq. Bras. Med. Vet. Zootec.*, v.76, n.2, p.357-366, 2024**

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

[*Fluxo de calor sensível e latente de codornas japonesas mantidas em diferentes ambientes térmicos*]

J.J.L. *Matos Júnior*[1], D.A. *Furtado*[2], N.L. *Ribeiro*[3], J.I. *Marques*[4], P.G. *Leite*[4],
J.W.B. *Nascimento*[2], V.P. *Rodrigues*[1], J.P. *Lopes Neto*[2], L.R. *Rodrigues*[1],
S.G.C. G. *Santos*[3], C.F.V. *Figueiredo*[5]

[1]Graduate, Universidade Federal de Campina Grande, PB, Brasil
[2]Universidade Federal de Campina Grande, Campina Grande, PB, Brasil
[3]Instituto Nacional do Semiárido, Campina Grande, PB, Brasil
[4]Universidade Federal do Maranhão, São Luís, MA, Brasil
[5]Instituto Federal do Sertão Pernambucano,Petrolina, PE, Brasil

ABSTRACT

This study aimed 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 32ºC.

Keywords: cloaca, convection, physiological parameters, radiation

RESUMO

O objetivo deste estudo foi estimar o fluxo de calor por meio de mecanismos sensíveis e evaporação respiratória de codornas japonesas mantidas em ambientes termoneutro e quente, utilizando medidas ambientais e fisiológicas simples. Foram utilizadas 192 codornas de nove semanas de idade, distribuídas em delineamento inteiramente ao acaso, em duas temperaturas (T1 = 24°C e T2 = 32°C), com 12 repetições de oito aves cada, com período experimental de 63 dias, divididas em três períodos de 21 dias. As medidas fisiológicas da frequência respiratória (FR), temperatura cloacal (TC) e temperatura da superfície corporal (TS) foram medidas duas vezes por semana. O comportamento do balanço energético nas câmaras climáticas foi obtido utilizando-se as trocas de energia térmica total por unidade de área superficial das aves, derivadas da soma das trocas de calor sensível (radiação e convecção) e latente. Frequência respiratória (P<0,0001), temperatura da superfície (P<0,0001) e temperatura cloacal (P=0,0047) foram maiores no ambiente de 32°C. A temperatura do ar expirado (P<0,0001) e a perda de calor por evaporação respiratória (P<0,0001) apresentaram valores maiores quando as codornas estavam em ambiente de 32°C, enquanto as perdas de calor por convecção (P<0,0001) e radiação (P<0,0001) foram maiores em um ambiente de conforto térmico. Em codornas japonesas mantidas em

---

Corresponding author: neilalr@hotmail.com
Submitted: December 6, 2022. Accepted: May 11, 2023.

ambiente controlado, a dissipação de calor sensível por convecção é a principal forma de eliminar o excesso de energia térmica, quando a temperatura do ar é de até 32ºC.

Palavras-chave: cloaca, convecção, parâmetros fisiológicos, radiação

INTRODUCTION

Quail breeding is an expanding activity in tropical regions, which are characterized by strong insulation, high air temperatures of up to 40ºC (Souza *et al.*, 2014), and sparse and irregular rainfall (Abdelsattar *et al.*, 2020). The Japanese quail is a bird adapted to hot climates, with small size, earliness, and productivity, requiring small spaces for production and little labor (Guimarães *et al.*, 2014; Khalilipour *et al.*, 2019). In quail 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). Quail of plumage plays a fundamental role in the thermal balance between the organism and the environment, so they directly interfere with 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 sensible means. Another form of heat exchange is latent exchanges, mainly evaporation, reflected in the bird as a form of panting (Silva, 2008).

This study aimed 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

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 (7º13'11"S; 35º53'31"W and 547m altitude). According to Köppen’s climate classification, the region's climate is tropical, with wet and dry seasons (AS'), maximum annual temperature of 32ºC and minimum of 17°C, and average annual precipitation of 765 mm.

The experiment was carried out in two climatic chambers, with dimensions of 3.07m x 2.77m x 2.6m, 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 an electric resistance air heater; hot/cold split air conditioning, Samsung brand, AS18UWBUXXAZ model, with the power of 1750W, and cooling capacity of 18,000 BTU/h, flow rate of 828m^3/h; and Britânia brand air humidifier, BUD04B model, with a capacity of 4.5L and a mist flow (average value) of 300ml h^{-1}. The relative humidity of the air was controlled by air humidifiers and measured by sensors. Ventilation was provided by 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 thermo-hygrometer anemometer (model LM-8000 AKSO® brand with measuring range: 0.4 to 30.0m/s and accuracy: ±3%). The chambers have temperature and humidity sensors, and environmental data were collected and recorded every 15min 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).

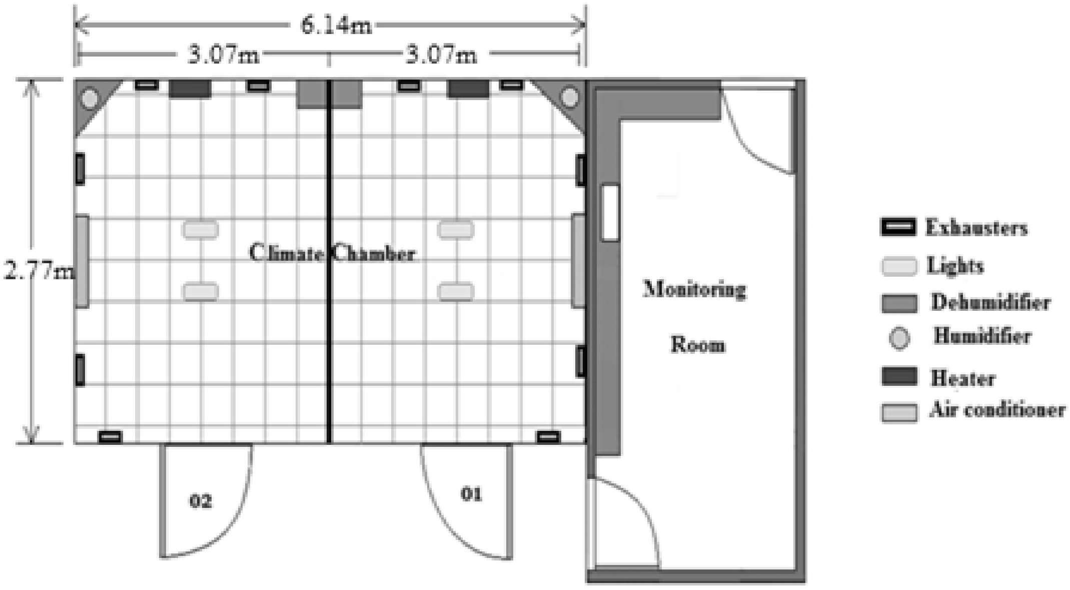

Figure 1. The internal layout of the climatic chambers where the quails were housed

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 an average 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 20cm (width, depth, and height, respectively), subjected to a stocking rate of 206cm^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 (24ºC) during the day and at room temperature at night. Egg production was counted, and, in 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±1.0ºC within the thermal comfort zone and 32±1.2ºC above the thermal comfort zone (Castro *et al.*, 2017; Soares *et al.*, 2019). 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±2.0ºC), 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±0.5m s^{-1}. The daily light program adopted was 17 hours of light and 7 hours of darkness, using 20W and 220V fluorescent lamps.

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.

Table 1. Bromatological chemical composition of the diets used in the experiment

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

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 a 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.* (2014):

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

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):

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

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).

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

Where,

CR - convection heat flux (W/m^2);
ρ - air density (kg/m^3);
Cp - specific heat of the 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.

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

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 the 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).

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

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.

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

Where,

Nu - Nusselt's number;
Re - Reynolds number.

The Reynolds number was obtained by Equation 8.

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

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.

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

Where,

L - radiant heat flux (W/m^2);
ρ - air density (kg/m^3);
Cp - specific heat of the air (J/kg °C);
Rr - resistance of the boundary layer to heat transfer by radiation (m^2 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:

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

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 the 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).

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

Where,

hc - globe convection coefficient;
Tg - black globe temperature (K).

The globe's convection coefficient was calculated by Equation 12

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

Where,
k - thermal conductivity of air (W/m K);
Pr - Prandtl's number, dimensionless.

Prandtl's number was obtained by Equation 13.

$P_r = \frac{\rho * C_p * v}{k}$ (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.

$E = \rho * V * (W_{ex} - W_a) * \lambda_s$ (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 Brown-Brandt (1997).

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.

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

Where,
e_a – 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:

$e_s = 0.6108 * 10^{\frac{7.5 * Ta}{237.3 + Ta}}$ (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).

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)

The means were compared by the Student test at 5% probability using the General Linear Model (GLM) procedure of SAS (2002). 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).

Table 3. Mean and standard deviation of physiological variables of Japanese quails submitted to two temperatures (24 and 32°C) in a climatic chamber

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
Cloacal 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.

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).

Table 4**.** Mean and standard deviation of the thermal exchanges of quails submitted to two temperatures (24 and 32°C) in a climatic chamber

Variables	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.

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).

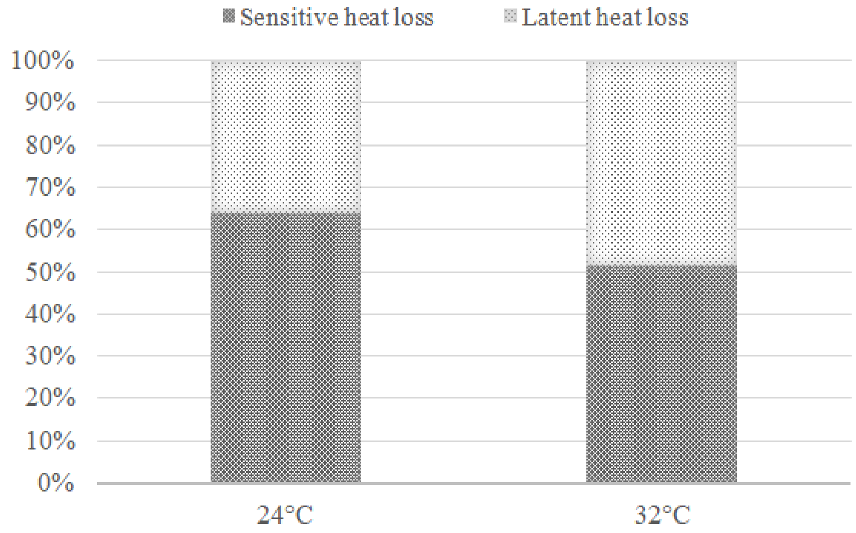

Figure 2**.** Participation of sensible and latent heat loss in Japanese quails in different thermal environments (24 e 32°C).

DISCUSSION

In environments with high temperatures, 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 agrees 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 quail eggs (Ribeiro *et al.*, 2016, Rodrigues *et al.*, 2016). Under heat stress conditions, an 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 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 42ºC] (Ribeiro *et al.*, 2016; Soares *et al.*, 2019). 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 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 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 to 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 optimal is to provide maximization of sensible losses, thus avoiding energy expenditure due to panting.

CONCLUSIONS

At the temperature of 32°C the physiological variables were higher, at this temperature, heat loss was more efficient in the evaporative form. Convection was more efficient than radiation and was more efficient at a temperature of 24°C.

ACKNOWLEDGEMENTS

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

REFERENCES

ABDELSATTAR, M.M.; HUSSEIN, A.M.A.; ABD EL-ATI, M.N. *et al.* Impacts of saline water stress on livestock production: a review. *Int. J. Agric. Sci.,* v.2, p.1-12, 2020.

ABU-DIEYEH, Z.H.M. Effect of high temperature *Per se* on growth performance of broilers. *Int. J. Poult. Sci*., v.5, p.19-21, 2006.

ALAGAWANY, M.; FARAG, M.R.; ABD EL-HACK, M.E. *et al*. Heat stress: effects on productive and reproductive performance of quail. *World's Poult. Sci. J.*, v.73, p.747-756, 2017.

BORGES, S.A.; MAIORKA, A.; SILVA, A.V.F. Fisiologia do estresse calórico e a utilização de eletrólitos em frangos de corte. *Ciênc. Rural,* v.33, p.975-981, 2003.

BROWN-BRANDT, T.M.; YANAGI JÚNIOR, T.; XIN, H. *et al.* Physiological responses of tom turkeys to temperature and humidity change with age. *J. Thermal. Biol.,* v.22, p.43-52, 1997.

BROWN-BRANDTL, T.M.; XIN, H.; BUCKLIN, R.A. *et al*. A new telemetry system for measuring core body temperature in livestock and poultry. *Appl. Eng. Agric.*, v.19, p.583-589, 2003.

CAMERINI, N.L.; SILVA, R.C.; NASCIMENTO, J.W.B. *et al*. Variação da temperatura superficial de aves poedeiras criadas em dois sistemas de criação utilizando termografia. *Agropecu. Cient. Semiárido,* v.12, p.145-152, 2016.

CÂNDIDO, M.G.L.; TINÔCO, I.F.F.; ALBINO, L.F.T. *et al*. Effects of heat stress on pullet cloacal and body temperature. *Poult. Sci.*, v.99, p.2469-2477, 2020

CASTRO, J.O.; YANANGI JUNIOR, T.; FERRAZ, P.F.P. *et al.* Japanese laying quail's behavior under different temperatures. *Energia Agric.,* v.32, p.141-147, 2017.

DAHLKE, F.; GONZALES, E.; GADELHA, A.C. *et al*. Empenamento, níveis hormonais de triiodotironina e tiroxina e temperatura corporal de frangos de corte de diferentes genótipos criados em diferentes condições de temperatura. *Ciênc. Rural,* v.35, p.664-670, 2005.

FURLAN, R.L.; MACARI, M. Termorregulação. In: MACARI M, FURLAN RL, GONZALES E. *Fisiologia aviária aplicada a frangos de corte*. 2.ed. Jaboticabal (SP): FUNEP/UNESP, 2002. 375p.

GUIMARÃES, M.C.C.; FURTADO, D.A.; NASCIMENTO, J.W.B. *et al.* Effect of season on production performance of quail in the semiarid region of Paraiba state, Brazil. *Rev. Bras. Eng. Agríc.Ambiental,* v.18, p.231-237, 2014.

HELLICKSON, M.A.; WALKER, J.N. *Ventilation of agricultural structures*. St. Joseph: ASABE, 1983. 372p.

KHALILIPOUR, G.; MAHERI, N.S.; SHADDDEL, A.T. Effects of saline drinking water on growth performance and mortality rate of Japanese quails (*Coturnix Japonica*). *J. Agric. Nat.,* v.22, p.942-947, 2019.

MALHEIROS, R.D.; MORAES, V.M.B.; BRUNO, L.D.G. *et al*. Environmental temperature and cloacal and surface temperatures of broilers chicks in first week post hatch. *J. Appl. Poult. Res.,* v.9, p.111-117, 2000.

MCARTHUR, A.J. Thermal interaction between animal and microclimate: a comprehensive model. *J. Theor. Biol.*, v.126, p.203-238, 1987.

MITCHELL, H.H. The surface area of single comb white leghorn chickens. *J. Nutr.*, v.2, p.443-449, 1930.

MOURA, P.S.; FURTADO, D.A.; SOUZA, J.F. Temperatura superficial e emissão de calor sensível de codornas japonesas mantidas em diferentes temperaturas. In: CONGRESSO TÉCNICO CIENTÍFICO DA ENGENHARIA E DA AGRONOMIA, 73., 2016, Foz do Iguaçu. *Anais*... Foz do Iguaçu: CONTECC, 2016.

MURAKAMI, A.E.; ARIKI, J. *Produção de codornas japonesas.* Jaboticabal: FUNEP, 1998. 79p.

NASCIMENTO, G.R.; NÄÄS, I.A.; PEREIRA, D.F. *et al*. Assessment of broiler surface temperature variation when exposed to different air temperatures. Braz. *J. Poult. Sci.*, v.13, p.259-263, 2011.

NASCIMENTO, S.T.; SILVA, I.J.O. As perdas de calor das aves: entendendo as trocas de calor com o meio. 2010. Disponível em: http://www.avisite.com.br/cet/img/2010916_trocasdecalor.pdf. Acessado em: 20 nov. 2021.

NASCIMENTO, S.T.; SILVA, I.J.O.; MAIA, A.S.C. *et al.* Mean surface temperature prediction models for broiler chickens-a study of sensible heat flow. *Int. J. Biometeorol.*, v.58, p.195-201, 2014

RIBEIRO, T.L.A.; SOUZA, B.B.; BRANDÃO, P.A. *et al*. *Different levels of protein and energy on physiological behavior and performance of European quail in the Brazilian semiarid. J. Anim. Behav. Biometeorol.*, v.4, p.76-83, 2016.

RODRIGUES, L.R.; FURTADO, D.A.; COSTA, F.G.P. *et al*. Thermal comfort index, physiological variables and performance of quails fed with protein reduction. *Rev. Bras. Eng. Agríc. Ambient.*, v.20, p.378-384, 2016.

ROSTAGNO, H.S.; ALBINO, L.F.T.; DONZELE, J.L. *et al*. *Brazilian tables for poultry and swine* - composition of feedstuffs and nutritional requirements. 3.ed. Viçosa: UFV, 2011. 251p.

SANTOS, S.M.; TINÔCO, I.F.F.; BARRETO, S.L.T. *et al*. Determination of upper limits of the thermal comfort zone for quails acclimatized in Brazil 22-35 days old. *Rev. Bras. Saúde Prod. Anim.*, v.15, p.350-360, 2014.

SANTOS, T.C.; GATES, R.S.; TINÔCO, I.F.F. *et al.* Productive performance and surface temperatures of Japanese quail exposed to different environment conditions at start of lay. *Poult. Sci.*, v.98, p.2830-2839, 2019.

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

SILVA, R.G. *Introdução a bioclimatologia animal.* São Paulo: Nobel, 2000. 288p.

SILVA, R.G. *Introdução à bioclimatologia animal*. São Paulo: Nobel, 2001.

SILVA, R.G. *Biofísica ambiental – os animais e seu ambiente*. Jaboticabal: Funep, 2008. 450p.

SILVA, RC.; NASCIMENTO, J.W.B.; RODRIGUES, L.R. *et al*. Quality of quail eggs confined in thermoneutral environment and heat stress. *J. Anim. Behav. Biometeorol.*, v.5, p.139-143, 2017.

SOARES, K.O.; SARAIVA, E.P.; SANTOS, J.D.C. *et al.* Effect of ambient temperature on the production parameters and egg quality of Japanese quail (*Cortunix japonica*). *Biol. Rhythm Res.*, v.52, p.1130-1137, 2019.

SOUSA, M.S.; TINÔCO, I.F.F.; BARRETO, S.L.T. *et al*. Determination of upper limits of the thermal comfort zone for quails acclimatized in Brazil 22-35 days old. *Rev. Bras. Saúde Prod. Anim.*, v.15, p.50-360, 2014.

SOUZA-JUNIOR, J.B.F.; EL-SABROUT, K.; ARRUDA, A.M.V. *et al.* Estimating sensible heat loss in laying hens through thermal imaging. *Comp. Electron. Agric.*, v.166, p.105038, 2019.

TURNPENNY, J.R.; MCARHTUR, A.J.; CLARK, J.A. *et al*. Thermal balance of livestock, 1. A parsimonious model. *Agric. Forest Meteorol.*, v.101, p.15-27, 2000.