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Modelagem fatorial das exigências energéticas de codornas japonesas na fase inicial e de crescimento

Factorial Modeling of Energy Requirements of Japanese Quail in the Starter and Grower Phases

Modelado factorial de los requerimientos energéticos de codornices japonesas en las fases inicial y de crecimiento

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Resumo

Este estudo quantificou as exigências de energia metabolizável aparente (EM) para mantença e ganho em codornas japonesas fêmeas de 1-35 dias de idade, combinando a metodologia fatorial com a técnica de abate comparativo. Utilizaram-se 655 codornas em duas fases: inicial (1-14 dias) e crescimento (15-35 dias). Para mantença as codornas nas gaiolas receberam 100, 75, 50 ou 25% do consumo *ad libitum*; para ganho, realizaram-se abates de referência e sequenciais. Registraram-se o consumo de ração, o consumo de energia metabolizável (E_{con}), o peso da carcaça em jejum (PCJ), a energia da carcaça (E_c), a energia na matéria seca da carcaça (E_{MS}), a energia retida (E_{ret}) e a produção de calor (PC). A EM de mantença (E_m) foi estimada por regressões lineares de E_{ret} em função de E_{con}, corrigida para o peso metabólico ($PV^{0,67}$); a energia líquida de mantença (EL_m) foi derivada das regressões de PC em função de E_{con}. Na fase inicial, E_m = 54,96 kcal/kg^{0,67}/dia e a eficiência de uso da EM para ganho (*k*) foi 16,92%; no crescimento, E_m = 92,11 kcal/kg^{0,67}/dia e *k* = 21,27%. A EL_m foi 53,27 e 57,88 kcal/kg^{0,67}/dia para as fases inicial e de crescimento, com eficiências de mantença (*km* = EL_m/E_m) de 96,93% e 62,84%. A energia líquida para ganho (EL_g) foi 1,40 e 1,896 kcal/g/dia, resultando em exigências dietéticas para ganho de peso de 8,30 e 8,91 kcal/g/dia. As equações foram: Inicial - EM (kcal/codorna/dia) = 54,96 × $PV^{0,67}$ + 8,30 × GP; Crescimento - EM (kcal/codorna/dia) = 92,11 × $PV^{0,67}$ + 8,91 × GP; em que PV é o peso vivo (kg) e GP o ganho de peso (g/codorna/dia). A temperatura ambiente média foi 24,05 °C (máx. 35,2 °C), evidenciando efeitos ambientais na mantença.

Palavras-chave: Balanço energético; Energia líquida; Equações de predição; Regressão linear.

Abstract

This study quantified the apparent metabolizable energy (ME) requirements for maintenance and gain in female Japanese quail (1-35 d of age) using a factorial approach combined with the comparative slaughter technique. A total of 655 quail were evaluated across two phases: starter (1-14 d) and grower (15-35 d). For maintenance, caged quail were offered 100, 75, 50, or 25% of *ad libitum* intake; for gain, reference and sequential serial slaughters were conducted. Recorded variables included feed intake, ME intake (ME_i), fasted carcass weight (FCW), carcass energy (C_E), energy in carcass dry matter (E_{DM}), retained energy (R_E), and heat production (HP). The ME requirement for maintenance (ME_m) was estimated by linear regressions of R_E on ME_i and expressed per metabolic body weight ($BW^{0.67}$); net energy for maintenance (NE_m) was derived from regressions of HP on ME_i. In the starter phase, ME_m = 54.96 kcal.kg$^{-0.67}$.d^{-1} and the efficiency of ME use for gain (*k*) was 16.92%; in the grower phase, ME_m = 92.11 kcal.kg$^{-0.67}$.d^{-1} and *k* = 21.27%. NE_m was 53.27 and 57.88 kcal.kg$^{-0.67}$.d^{-1} for starter and grower, yielding maintenance efficiencies (*km* = NE_m/ME_m) of 96.93% and 62.84%. Net energy for gain (NE_g) was 1.40 and 1.896 kcal.g^{-1}.d^{-1}. resulting in dietary requirements for weight gain of 8.30 and 8.91 kcal.g^{-1}.d^{-1}, respectively. The prediction equations were Starter - ME (kcal.quail^{-1}.d^{-1}) = 54.96 × $BW^{0.67}$ + 8.30 × WG; Grower - ME (kcal.quail^{-1}.d-^{1}) = 92.11 × $BW^{0.67}$ + 8.91 × WG; where BW is live body weight (kg) and WG is daily weight gain (g.quail^{-1}.d^{-1}). Mean ambient temperature was 24.05°C (max 35.2°C), suggesting environmental effects on maintenance requirements.

Keywords: Energy balance; Net energy; Prediction equations; Linear regression.

Resumen

Este estudio cuantificó los requerimientos de energía metabolizable aparente (EM) para mantenimiento y ganancia en codornices japonesas hembras de 1-35 días de edad, combinando la metodología factorial con la técnica de sacrificio comparativo. Se utilizaron 655 aves en dos fases: inicial (1-14 días) y crecimiento (15-35 días). Para mantenimiento, las aves en jaulas recibieron 100, 75, 50 o 25% del consumo ad libitum; para ganancia, se realizaron sacrificios de referencia y secuenciales. Se registraron el consumo de alimento y la ingesta de EM (EM_i), el peso de la canal en ayuno (PCA), la energía de la canal (E_C), la energía en la MS de la canal (E_{MS}), la energía retenida (E_R) y la producción de calor (PC). La EM para mantenimiento (E_m) se estimó mediante regresiones lineales de E_R en función de EM_i y se expresó por peso metabólico ($PV^{0,67}$); la energía neta de mantenimiento (EN_m) se derivó de las regresiones de PC en función de EM_i. En la fase inicial, Em = 54,96 kcal/kg/^{0,67}/día y la eficiencia de uso de la EM para ganancia (*k*) fue 16,92%; en crecimiento, Em = 92,11 kcal/kg/^{0,67}/día y *k* = 21,27%. La EN_m fue 53,27 y 57,88 kcal/kg/^{0,67}/día para las fases inicial y de crecimiento, con eficiencias de mantenimiento ($km = EN_m/E_m$) de 96,93% y 62,84%. La energía neta para ganancia (EN_g) fue 1,40 y 1,896 kcal/g/dia, resultando en requerimientos dietéticos para ganancia de peso de 8,30 y 8,91 kcal/g/dia. Las ecuaciones de predicción fueron: Inicial - EM (kcal/codorniz/día) = $54,96 \times PV^{0,67} + 8,30 \times GP$; Crecimiento - EM (kcal/codorniz/día) = $92,11 \times PV^{0,67} + 8,91 \times GP$; donde PV es el peso vivo (kg) y GP la ganancia de peso diaria (g/codorniz/día). La temperatura ambiente media fue 24,05 °C (máx. 35,2 °C), indicando efectos ambientales sobre los requerimientos de mantenimiento.

Palabras clave: Balance energético; Energía neta; Ecuaciones de predicción; Regresión lineal.

1. Introduction

Quail farming in Brazil in the year 2018 reached a total of 16.8 million head, either for meat or for eggs, and 297.3 million dozen eggs, representing an increase of 3.9% compared to the year 2017, while the production of quail eggs fell 2.1% (IBGE, 2019).

Several methodologies applied to chickens and laying hens (Sakomura and Rostagno, 2016) are effective in quail use, however the characteristics of the species must be considered to avoid biased estimates of nutritional requirements. Quail, whether intended for laying or cutting, have early maturity, and are related to growth rate, and to size of animals (Tholon et al., 2012; Drumond et al., 2013; Mota et al., 2015; Demuner et al., 2017; Grieser et al., 2017; Grieser et al., 2018), thus, smaller animals have higher growth rates and lower age to maturity.

Precocity in growth is related to the time the animal takes to achieve sexual maturity and is a guiding parameter in breeding programs. Smaller animals have higher growth rates and a lower age to maturity. Thus, defining energy requirements in Japanese quail requires considering growth and thermoregulation traits specific to the species.

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The factorial method for estimating the requirements differs from the empirical method because it is possible to estimate the requirements by the product between the size of the nutrient required by the animal and its efficiency of use (*k*). This allows partitioning requirements into maintenance and production (gain), which improves the understanding of animal metabolism (Oviedo-Rondón and Waldroup, 2002).

The development of prediction models based on the factorial methodology gains importance due to the flexibility and simplicity of application and due to the possibility of estimating requirements for different phases and categories using routine balances (Silva et al., 2004a, 2004b; Filho et al., 2011a, 2011b).

Among the different models for predicting nutritional requirements based on the factorial methodology, some authors propose expressing maintenance as a function of the ¾ power of weight, that is, they suggest metabolic weight ($BW^{0.75}$). Dodds (2001), in an extensive review on the topic, suggests that for quail the use of $BW^{0.67}$ (surface law) is more appropriate than $BW^{0.75}$, due to the relationship between heat exchange and body surface area.

Few data are available on the requirements of Japanese quail, especially those that fraction the energy for maintenance and for gain, for 1-14 and 15-35 d, using the factorial methodology.

2. Materials and Methods

The experiment was carried out at the Center for Agricultural Sciences (CCA), Federal University of Northern Tocantins (UFNT), Araguaína, Tocantins, Brazil. It was conducted from November 19 to December 22, 2019. The research project was approved and registered by the UFT Animal Use Ethics Committee, under protocol no. 23.101.00179/2.017-53.

The experimental shed had blue side curtains and was equipped with 24 galvanized wire cages. The cages measured 0.52 × 0.51 × 0.30 m (0.026 m²/quail) and each had a 70-W incandescent lamp. Quail assigned to the maintenance-requirement experiment were housed in these cages.

Quail designated to establish energy requirements for gain were placed on the floor, which was covered with wood chips. The shed had 70-watt incandescent lamps, drinking fountains, and pressure feeders. The water and diet were provided *ad libitum* for the quail present in this environment. A commercial digital hygrometer was used to measure the temperature and humidity inside the shed during the experimental period.

To estimate the metabolizable energy requirements for maintenance (E_m) and weight gain (E_g) in the phases from 1-14 and 15-35 d of age, the comparative slaughter technique was adopted (Sakomura and Rostagno, 2016)

A total sample of 655 female Japanese quail was used. The experiment was divided into two parts: starter (1-14 d), using 350 quail with a starter average body weight of 6.58 ± 0.28 g (mean ± SD) 240 were housed in cages, 75 on the floor, and 35 were slaughtered at 1 d as the reference group; and grower (15-35 d), using 305 quail with a starter average body weight of 48.31 ± 0.16 g. 240, 40, and 25 quail corresponded to the maintenance, gain, and reference slaughter groups, respectively.

The quail used to estimate maintenance in the starter and growing phases were distributed in the cages and received treatments according to a completely randomized design, with four levels of feed supply (ad libitum, 75, 50 and 25% of consumption ad libitum) with six replicates of ten quail per experimental unit. The experimental diets in each phase were formulated according to Rostagno et al. (2017) recommendations (Table 1).

To estimate the energy gain requirements in the starter phase (1-14 d), 15 quail were slaughtered (3; 6; 9; 12 and 15 d). In the grower phase (15-35 d), 10 quail were slaughtered every five d (on d 20, 25, 30, and 35).

In each test, quail destined for slaughter were fasted from solids for 12 h, reweighed, and slaughtered by cervical dislocation, to avoid loss of blood and feathers. The slaughtered carcasses were identified, placed in plastic bags, stored in the freezer, and then ground twice in a cutter meat grinder, weighed, and placed in a forced-ventilation oven at 55°C for approximately 72 hours for predrying and subsequent grinding. Then, the samples were processed two more times in the "cutter" mill and once in the "Wiley" mill to obtain more homogeneous samples for further chemical analysis (AOAC**,** 2019).

Table 1. Chemical composition and percentage of experimental diets.

Ingredients	01-14 d - **(g/kg)**	15-35 d - **(g/kg)**
Corn	578.05	598.11
Soybean meal	368.62	360.82
Degummed oil	12.78	7.63
Dicalcium phosphate	22.07	17.49
Calcitic limestone	10.99	9.23
Common salt	4.83	5.06
DL-Methionine 99%	1.61	1.13
L-Lysine HCl 78.4%	0.63	0.05
L-Threonine 98.5%	0.02	0.09
Premix[†]	0.40	0.40
Total	1000.0	1000.0
Metabolizable energy (MJ/kg)	12.13	12.13
Electrolytic balance (mEq/kg)	204.5	290.35

Nutrients	Chemical composition (g/kg)	
Crude protein	212.8	210.9
Calcium	10.92	9.11
Available phosphorus	5.13	4.28
Sodium	2.05	2.14
Potassium	8.60	8.52
Chlorine	3.71	3.74
Digestible amino acids	**Chemical composition (g/kg)**	
Lysine	10.95	10.34
Methionine + cystine	7.44	6.93
Threonine	7.33	7.34
Valine	8.98	8.89
Isoleucine	8.35	8.26
Tryptophan	2.45	2.42
Arginine	13.43	13.26
Histidine	5.22	5.18
Glycine + serine	17.34	17.16
Phenylalanine + tyrosine	17.22	17.05
Leucine	16.80	16.74

†Composition: Manganese, 200.0 g/kg; zinc, 150.0 g/kg; iron, 125.0 g/kg; copper, 20.0 g/kg; iodine, 3.75 g/kg; selenium, 0.75 g/kg; vitamin A, 25,000,000 IU/kg; vitamin D_3, 5,000,000 IU/kg; vitamin E, 75.0 g/kg; vitamin K_3, 7.5 g/kg; thiamine (B_1), 5.0 g/kg; riboflavin (B_2), 15.0 g/kg; niacin, 100.0 g/kg; pantothenic acid (B_5), 30.0 g/kg; folic acid, 2.5 g/kg; cyanocobalamin (B_{12}), 0.0375 g/kg; antioxidant, 187.5 g/kg; carriers/flow agents, q.s. to 1,000 g/kg. Additional additives: choline chloride (60% active) at 0.83 g/kg diet; salinomycin (12% activity) at 0.50 g/kg diet. Source: Authors.

At the end of each phase, the quail were fasted from solids for 12 h, reweighed, and slaughtered by cervical dislocation, to avoid loss of blood and feathers, to allow the evaluation of the deposition of nutrients in the carcass.

With the data obtained, it was possible to calculate feed intake (FI – $g.quail^{-1}.d^{-1}$), energy consumption (E_{con} – $kcal.quail^{-1}.d^{-1}$), energy in carcass dry matter (E_c – $kcal.g^{-1}.DM^{-1}$), carcass energy (C_e – $kcal.g^{-1}$), energy retention (E_{ret} – $kcal.g^{-1}.d^{-1}$) and fasting carcass weight (FCW – $g.quail^{-1}$). The energy requirement for maintenance (E_m) was obtained by linear regression of energy retention (E_{ret}) as a function of energy consumption (E_{con}). By extrapolating to zero energy retention, the maintenance requirement was given by the ratio a/b, expressed per unit of metabolic weight ($BW^{0.67}$) (Dodds, 2001). The efficiency of energy use (k) was given by parameter b. The parameter a (intercept), corrected for metabolic weight, represents endogenous loss of body energy.

The net energy for maintenance (NE_m) was estimated by the comparative slaughter method, from the relationship between heat production (HP) and consumption (E_{con}). For each treatment, HP was obtained by difference ($HP = E_{con} - E_{ret}$). Exponential regression was fitted, $HP = a \times \exp^\wedge(b \times E_{con})$ ($kcal.quail^{-1}.d^{-1}$, also expressed per $BW^{0.67}$). By extrapolating the line to $E_{con} = 0$, the intercept on the y-axis (parameter a) estimates fasting heat production, which, under thermoneutral conditions, is taken as NE_m. The efficiency of using energy for

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maintenance (k_m) was calculated as the ratio of net to metabolizable maintenance energy: $k_m = NE_m / E_m$.

To estimate the metabolizable energy requirements for maintenance (E_m) and weight gain (E_g) in 1-14 and 15-35 d, the comparative slaughter technique was adopted (Sakomura and Rostagno, 2016). For this, a group of 35 quail (starter) were slaughtered at 1 d (reference slaughter), and all quail in the plots were slaughtered at the end of the experiment when the quail were 15 d. For the grower, a group of 25 quail was slaughtered at 15 d (reference slaughter), and all quail in the plots were slaughtered at the end of the experiment when the quail reached 35 d.

The residuals were subjected to the Kolmogorov–Smirnov normality test ($\alpha = 0.05$). The homogeneity of variances was evaluated by Levene's test ($\alpha = 0.05$), and all variables exhibited a normal distribution of errors and homoscedasticity. Linear models were estimated to use SAS 9.0 (PROC REG) at $\alpha = 0.05$. All proposed models showed a significant effect (t-test, $\alpha = 0.05$) on the parameters β_0 and β_1, with $\alpha = 0.05$.

To avoid ambiguity, we adopt two energy efficiencies: maintenance efficiency (k_m), defined as the fraction of metabolizable energy (ME) effectively used to meet maintenance requirements; and gain efficiency (k), defined as the fraction of ME above maintenance that is converted into energy retained (E_{ret}) in the body. Both are dimensionless and are reported as percentages throughout the text.

Air temperature averaged 24.05°C (min 22.1°C; max 35.2°C). Relative humidity averaged 84.9% (min 73%; max 95%).

3. Results and Discussion

Table 2 shows marked decreases in fasted carcass weight, feed intake, metabolizable energy intake, retained energy, gross body energy, and heat production across ages and feed-supply levels in Japanese quail. Similar patterns have been reported previously (Silva et al., 2004a, 2004b; Longo et al., 2006; Filho et al., 2011a, 2011b; Sakomura et al., 2005).

Table 2. Fasting carcass weight (FCW – $g.quail^{-1}$), energy consumption (E_{con} – $kcal.quail^{-1}.d^{-1}$), gross carcass energy (E_C – $kcal.g^{-1}.DM^{-1}$), gross body energy (C_e – $kcal.g^{-1}$), retained energy (E_{ret} - $kcal.g^{-1}.d^{-1}$) and Heat production (HP - $kcal.g^{-1}.d^{-1}$) of Japanese quail according to age, feed supply levels (FSL - %), reference slaughter (RS).

	Maintenance (01-14 d)					
RS (1° d)	FCW	E_{con}	E_c	C_e	E_{ret}	†HP
	6.71	-	1.25	8.35	-	-

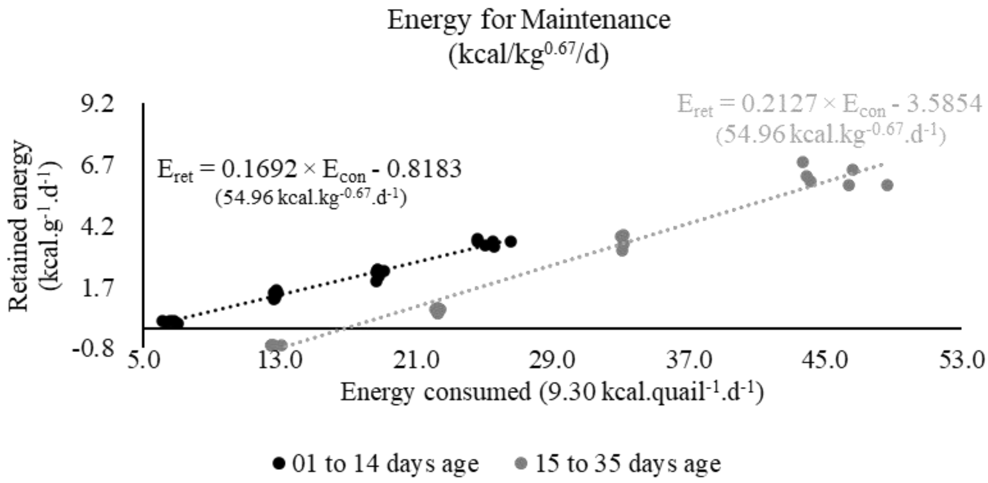
FSL	Final Slaughter - 15º d					
100	46.36±0.60	25.32±0.74	1.24±0.03	57.48±1.77	3.51±0.13	21.81±0.79
75	34.97±1.16	18.77±0.16	1.14±0.06	40.04±2.54	2.26±0.18	16.51±0.22
50	24.33±1.33	12.74±0.09	1.14±0.02	27.86±1.98	1.40±0.14	11.34±0.14
25	12.89±0.77	6.62±0.32	0.96±0.01	12.34±0.74	0.29±0.05	6.34±0.36
Age (d)	Gain (01-14 d)					
01	6.71	-	1.25	8.37	-	-
03	8.33	-	1.08	8.98	-	-
06	14.67	-	1.16	17.06	-	-
09	24.33	-	1.33	32.25	-	-
12	34.33	-	1.35	46.20	-	-
15	48.40	-	1.36	65.64	-	-
	Maintenance (15-35 d)					
RS (15º d)	FCW	E_{con}	E_c	C_e	E_{ret}	†HP
	48.40	-	1.356	65.65	-	-
FSL	Final Slaughter - 35º d					
100	110.75±2.50	45.57±1.98	1.72±0.08	189.86±7.44	6.21±0.37	39.36±2.20
75	98.13±7.15	33.11±0.07	1.40±0.11	136.87±5.82	3.56±0.29	29.54±0.32
50	65.45±1.40	22.28±0.09	1.23±0.02	80.67±1.61	0.75±0.08	21.53±0.13
25	43.00±0.15	12.64±0.22	1.21±0.01	52.28±0.09	-0.67±0.10	13.31±0.22
Age (d)	Gain (15-35 d)					
15	48.40	-	1.36	65.64	-	-
20	70.00	-	1.54	107.51	-	-
25	90.50	-	1.57	142.48	-	-
30	97.00	-	1.58	153.44	-	-
35	102.50	-	1.69	173.14	-	-

†HP = E_{con} - E_{ret}. Source: Authors.

A drop in the feed consumption of the quail, and consequently, a drop in energy intake accompany the drop observed in these variables (Table 2). This finding is relevant and valid for the method used to understand the phases of animal metabolism: maintenance and weight gain in the phases 1-14, and 15-35 d.

The estimated maintenance requirement (Figure 1) in the starter phase (1-14 d) was 54.96 $kcal.kg^{-0.67}.d^{-1}$ ($R_E = (0.1692 \pm 0.004) \times E_{con} - (0.8183 \pm 0.082)$; $R^2 = 0.98$; $BW^{0.67} = 0.088$ $kg.quail^{-1}$). In the grower phase (15-35 d), the requirement was 92.11 $kcal.kg^{-0.67}.d^{-1}$ ($R_E = (0.2127 \pm 0.007) \times E_{con} - (3.5854 \pm 0.232)$; $R^2 = 0.97$; $BW^{0.67} = 0.183$ $kg.quail^{-1}$).

Figure 1. Relationship between energy retention in the carcass and metabolizable energy consumption of Japanese quail from 01-14 and 15-35 d



Source: Authors.

Silva et al. (2004a) for quail in the starter (1-12 d) estimated maintenance at 77.07 $kcal.kg^{-0.75}.d^{-1}$. For the 15 to 32-d phase, Silva et al. (2004b) estimated values of 91.48 $kcal.kg^{-0.75}.d^{-1}$, Filho et al. (2011a) for Japanese quail in the grower (16-36 d) estimated maintenance at $(98.37 - 0.205 \times T) \times BW^{0.75}$ and European quail at $(115.08 - 0.3939 \times T) \times BW^{0.75}$. This research was made with quail housed in cages.

These values differ from those reported by Silva et al. (2004a, 2004b) and Filho et al. (2011a), who used $BW^{0.75}$ (3/4-power) rather than $BW^{0.67}$ (2/3-power). The use of $BW^{0.67}$ is consistent with surface-area scaling in birds (Dodds et al., 2001).

According to Dodds (2001), in quail the metabolic rate scales to body mass raised to the 2/3 power, consistent with surface area dependence. In the starter phase (1-14 d), quail offered 25% of ad libitum intake showed an endogenous energy loss of approximately 3.29 $kcal.kg^{-0.67}.d^{-1}$. In the grower phase (15-35 d), negative retained energy was observed, with endogenous losses around 7.61 $kcal.kg^{-0.67}.d^{-1}$ under the most severe restriction (25% of *ad libitum*).

This response can be explained by the apparent metabolizable energy (AME) requirement for maintenance (MEm) being about 54.96 $kcal.kg^{-0.67}.d^{-1}$ in the starter phase and 92.11 $kcal.kg^{-0.67}.d^{-1}$ in the grower phase; therefore, the higher requirement in the grower period, combined with feed restriction, increases mobilization of body reserves (catabolism) to supply energy. These findings support the need to estimate maintenance requirements by age phase in Japanese quail.

Thermal control by heating in the starter phase and exposure to temperatures up to 35.2°C with ventilation only in the grower phase suggest an environmental impact on the apparent metabolizable energy (AME) requirement for maintenance (MEm) via adjustments in homeothermy. In the starter phase, MEm = 54.96 $kcal.kg^{-0.67}.d^{-1}$, about 40% lower than in the grower phase (MEm = 92.11 $kcal.kg^{-0.67}.d^{-1}$), indicating a lower maintenance cost when the environment was heated to preserve homeothermy. In the grower phase, the hot environment likely increased the need for heat dissipation and thus the maintenance cost. Under severe feed restriction (25% of ad libitum), negative retained energy was observed, with endogenous losses of approximately 3.29 $kcal.kg^{-0.67}.d^{-1}$ (1-14 d) and 7.61 $kcal.kg^{-0.67}.d^{-1}$ (15-35 d), reinforcing the influence of thermal environment and restriction on energy balance. Although drinking water temperature was maintained near 21°C, this factor likely only partially mitigated heat stress and did not eliminate the effect of high ambient temperature in the second phase.

In the works of Silva et al. (2004a, 2004b) the values were closer (77.07 vs 91.48 $kcal.kg^{-0.75}.d^{-1}$), this difference was attributed to the difference in the weight of the quail in the two phases studied by Silva et al. (2004a, 2004b).

Comparing energy-use efficiencies (*k*), we observed 16.92% (starter) and 21.27% (grower). These results contrast with Silva et al. (2004a, 2004b), who reported higher efficiency in the first phase (1-12 d) relative to the second (15-32 d): 28.56% vs. 23.60%.

Filho et al. (2011a) observed the efficiency in the use of diet energy at around 17% to 25% for quail housed, respectively, at temperatures of 18, 24, and 28ºC. For quail at room temperature and housed in Filho et al. (2011a), they registered 23% efficiency. All the efficiencies compared were greater than those presented in this research were.

It is inferred that the lesser use of energy, by quail in this research in the first phase, may be related to the absolute digestive capacity of quail. Iji et al. (2001)reported that the maximum relative growth of the intestine occurs up to seven d, however, and Grieser et al. (2015) demonstrate that the maximum absolute weight occurs at 20 d, that is, greater volumetric capacity and capacity to obtain energy from the feed. The rapid relative growth of the intestine up to seven d (Iji et al., 2001) did not reflect greater utilization, which may suggest that greater emptying of the intestine due to its lower absolute weight at this age, with this low total digestive capacity.

The ingested energy showed the efficiency of use as 16.92% and 21.27%, respectively, for the starter and grower. Albino et al. (1994), registered for chickens of lines EMB-011 and Lohmann 47% and 55%, respectively.

One explanation may be related to a greater loss of heat in relation to quail mass and body surface (Macleod and Dabhuta, 1997; Dodds, 2001), what in this research was related to 2/3. The lower relative weight of the quail intestine, consequently greater speed in the passage of feed (Cruz et al.,2019) may explain the lower digestive efficiency among quail, hens, and laying hens.

Another explanation is that quail are animals with wild habits, that is, they are more affected with the presence of human beings, or even, they present greater agitation and movement inside the installations/cages.

In Filho's (2011a) works, comparing Japanese quail housed (93.58 $kcal.kg^{-0.75}.d^{-1}$) in cages and on the ground (95.23 $kcal.kg^{-0.75}.d^{-1}$), it was evident that there is a greater need for energy for maintenance when animals have space to move, that is, raised on the ground in detriment of cages.

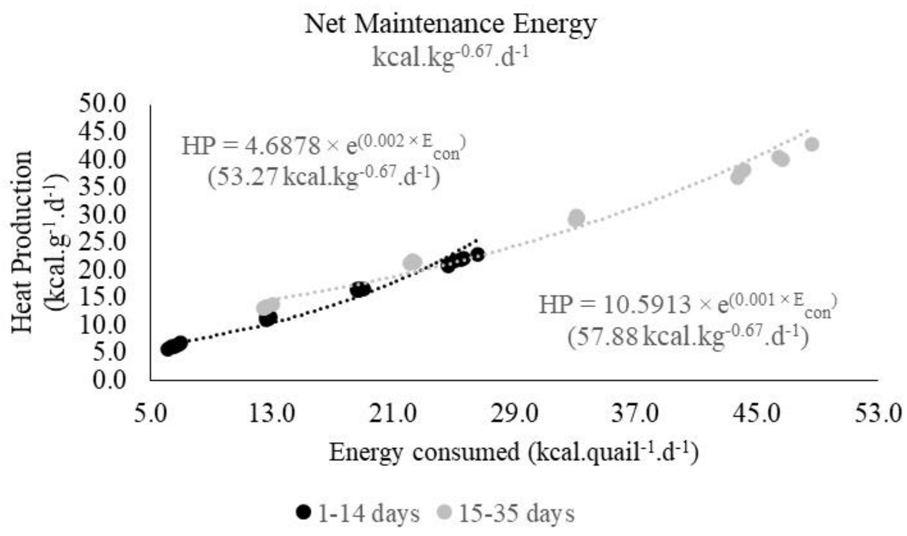
The above finding (present research) can be verified when comparing the efficiency of using energy for maintenance. Extrapolating to zero energy intake, the efficiencies for both phases were 96.93% and 62.84%, respectively (Figure 2), for the starter and grower. However, a difference between the phases was already expected, since quail in the second phase (15-35 d) have higher weight gains (Table 2).

The estimate of the net requirement energy (Figure 2) for maintenance was estimated by the exponential relationship of heat production and energy consumption (HP = (4.6878 ± 0.257) × exp^[(0.0528 ± 0.002) × Econ], R^2 = 0.99), expressed in a metabolic weight, of 53.27 $kcal.kg^{-0.67}.d^{-1}$. Therefore, it was possible to calculate the efficiency of use of E_m of the diet in NE_m as 96.93%.

The estimate of the net requirement (Figure 2) for maintenance was estimated by the exponential relationship of heat production and energy consumption (HP = (10.5913 ± 0.428) × exp^[(0.0291 ± 0.001) × Econ], R^2 = 0.99), expressed in a metabolic weight of 57.88 $kcal.kg^{-0.67}.d^{-1}$.

It was possible to calculate the efficiency (k_m) of use of E_m of the diet in NE_m as 62.84%. The maintenance requirement of 54.96 $kcal.kg^{-0.67}.d^{-1}$ was less than that observed by Albino et al. (1994), of 142 and 164 $kcal.kg^{-0.75}.d^{-1}$, respectively, for pullets of light lines EMB-011 and Lohmann LSL. Filho et al. (2011) observed values of (98.37 - 0.205 × T) $kcal.kg^{-0.75}.d^{-1}$.

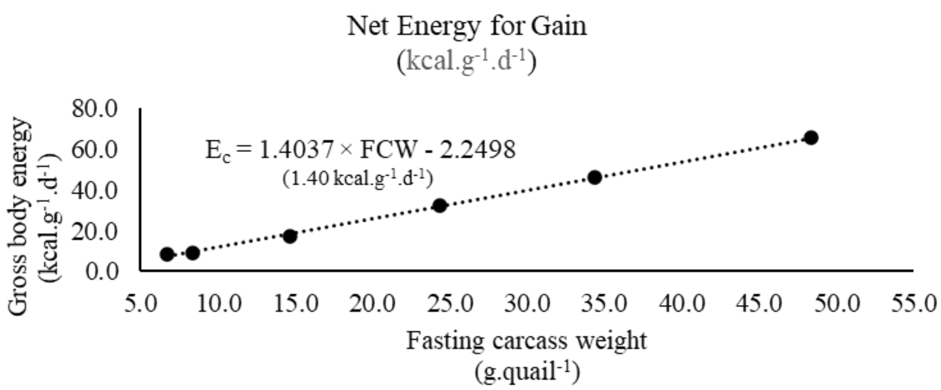
Figure 2. Relationship between heat production and metabolizable energy consumption of Japanese quail from 01-14 and 15-35-d



Source: Authors.

The net requirement for gain (NE_g) was estimated by the linear relationship between body energy retentions (Figure 3) over time (1; 3; 6; 9; 12; and 15 d) as a function of fasting carcass weight of quail and the following equation was obtained: $E_c = (1.4037 \pm 0.025) \times FCW - (2.2498 \pm 0.697)$, $R^2 = 0.99$ which was 1.40 kcal.g^{-1}.d^{-1}. The dietary requirement for gain was obtained through the NE_g ratio by the efficiency of use (*k*) of energy by the animals, resulting in 8.30 kcal.g^{-1}.d^{-1}.

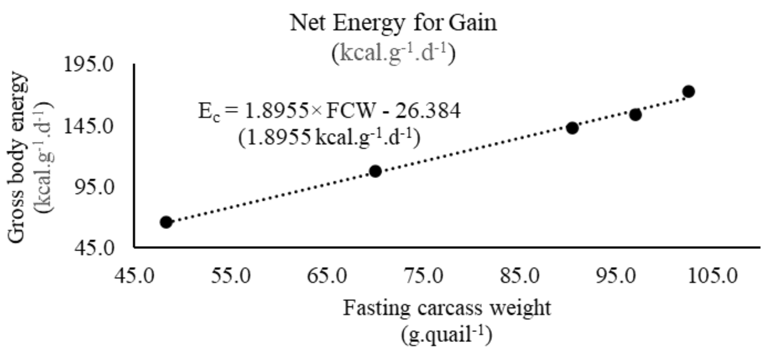
Figure 3. Relationship between gross body energy retained in the carcass over time as a function of fasting carcass weight of Japanese quail from 01-14 d



Source: Authors.

The net requirement for gain (NE_g) was estimated by the linear relationship between body energy retentions (Figure 4) over time (15; 20; 25; 30; and 35 d) as a function of the fasting carcass weight of the quail and the following equation was obtained: $E_c = (1.8955 \pm 0.094) \times FCW - (26.382 \pm 7.881)$, $R^2 = 0.99$ which was 1.896 kcal.g^{-1}.d^{-1}. The dietary requirement for gain was obtained through the NE_g ratio by the efficiency of use (k) of energy by the animals, resulting in 8.91 kcal.g^{-1}.d^{-1}.

Figure 4. Relationship between energy retained in the carcass over time as a function of fasting carcass weight of Japanese quail from 15-35 d



Source: Authors.

Silva et al. (2004a; 2004b) found values of dietary energy for weight gain respectively of 4.64 and 9.32 kcal.g^{-1}.d^{-1} for the phases of 1-12 and 15-32 d of Japanese quail. A 100.86% increase in the requirement. This difference must be the biggest weight gain in the grower (3.5 kcal.g^{-1}.d^{-1}) in relation to the starter (2.45 kcal.g^{-1}.d^{-1}) and also the smallest energy efficiency in the second phase (22%) compared to the first (28%). In this study, the dietary energy values required for weight gain were determined to be 8.30 kcal.g^{-1}.d^{-1} for ages 01-14 d and 8.91 kcal.g^{-1}.d^{-1} for ages 15-35 d, indicating a 7.47% increase over time.

The observed weight gains were greater in the first phase (2.78 g.quail^{-1}.d^{-1}) than in the second (2.71 g.quail^{-1}.d^{-1}). Along with the phase-specific k values (16.92% and 21.27%), this helps explain the smaller difference between dietary energy requirements for gain found here (8.30 vs. 8.91 kcal.g^{-1}.d^{-1}) compared with Silva's findings (4.64 vs. 9.32 kcal.g^{-1}.d^{-1}).

Finally, it is important that more research is carried out, as there is still little data available on the requirements of Japanese quail, based on the factorial methodology in the starter and grower with regard to energy.

4. Conclusion

The prediction equations to estimate daily maintenance and gain energy requirements in Japanese quail were: Starter - ME (kcal.quail^{-1}.d^{-1}) = 54.96 × BW$^{0.67}$ + 8.30 × WG; Grower - ME (kcal.quail^{-1}.d^{-1}) = 92.11 × BW$^{0.67}$ + 8.91 × WG; where W is body weight (kg) and WG is weight gain (g.quail^{-1}.d^{-1}).

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Conflict of interest

The authors declare that there is no conflict of interest.

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