

Metabolism and thermoregulation between Mrs Hume's Pheasant (*Syrmaticus humiae*) and Elliot's Pheasant (*S. ellioti*)

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Abstract: To understand metabolic adaptations, the basal metabolic rate (BMR) of Mrs Hume's Pheasant (*Syrmaticus humiae*) and Elliot's Pheasant (*Syrmaticus ellioti*) were investigated. Metabolic rate (MR), body temperature (T_b) and thermal conductance (C) were determined in both species at a temperature range of 5 – 35 °C, respectively. Oxygen consumption was measured with a closed circuit respirometer. The thermal neutral zones (TNZ) were 24.5 – 31.6 °C, and 23.0 – 29.2 °C, respectively. With a temperature range of 5 – 35 °C, Mrs Hume's Pheasant and Elliot's Pheasant could maintain stable T_b at a mean of (40.47±0.64) and (40.36±0.10) °C, respectively. Mean BMRs within TNZs were (1.36±0.84) mL O_2 /(g·h) for Mrs Hume's Pheasant and (2.03±0.12) mL O_2 /(g·h) for Elliot's Pheasant, which were 77% and 86% of the expected value based on their body mass, respectively. Thermal conductance of Mrs Hume's Pheasant and Elliot's Pheasant were (0.12±0.01) and (0.17±0.01) mL O_2 /(g·h·°C), below the lower critical temperature, respectively, which were 119% and 124% of the expected value based on their body mass, respectively. The ecophysiological characteristics of these species were low metabolic rate, high body temperature, and high thermal conductance, which allow both species to better adapt to the warmer climate environment in south China.

Key words: *Syrmaticus humiae*; *Syrmaticus ellioti*; Body temperature; Basal metabolic rate; Thermal conductance

笼养黑颈长尾雉和白颈长尾雉代谢产热特征及体温调节

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摘要: 采用封闭式流体压力呼吸仪, 在 5~35 °C 的环境温度范围内测定了黑颈长尾雉(*Syrmaticus humiae*)和白颈长尾雉(*Syrmaticus ellioti*)的代谢率(MR)、热传导(C) 和体温(T_b)等指标, 探讨了其代谢产热特征。结果显示: 黑颈长尾雉和白颈长尾雉的热中性区(TNZ)分别为 24.5~31.6 °C 和 23.0~29.2 °C。在 5~35 °C 的温度范围内, 黑颈长尾雉和白颈长尾雉能保持稳定的体温, 分别为(40.47±0.64)和(40.36±0.10) °C; 在热中性区内, 黑颈长尾雉和白颈长尾雉的平均基础代谢率(BMR)分别为(1.36±0.84)和(2.03±0.12) mL O_2 /(g·h), 分别是体重预期值的 77 %和 86%。在下临界温度以下, 黑颈长尾雉和白颈长尾雉的最小热传导分别是(0.12±0.01)和(0.17±0.01) mL O_2 /(g·h·°C), 分别是体重预期值的 119%和 124%。这两种鸟的生理生态学特征是: 黑颈长尾雉和白颈长尾雉都具有较低的代谢率, 较高的体温和热传导, 能较好地适应南方湿热的气候特征。

关键词: 黑颈长尾雉; 白颈长尾雉; 体温; 基础代谢率; 热传导

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Metabolism is one of the most basic animal characteristics, going with energy flowing and information communion in the course of substance metabolism. Metabolism is a major factors in all life processes, including energy utilization, and important part of life history (Williams & Tieleman, 2000). Bird metabolism affects distribution and abundance, which are considered major survival countermeasures (Weathers, 1997; Lovegrove, 2003). Basal metabolic rate (BMR) is the rate of energy transformation in a rested, awake and fasted state in the absence of thermal stress, and is the minimum metabolic rate of animals maintaining normal physiological function. It is important parameters of energy metabolism comparison (Jessen, 2001). The use of BMR as an index of energy expenditure has received a great deal of attention from environmental physiologists, ecophysiologists and comparative physiologists (Reynolds & Lee, 1996).

Comparative physiological ecology is important for developing general rules about birds through comparison. Most basal rate variation in bird metabolism can be explained by the combined influences of body size, phylogeny, climate condition, activity and feeding habits (McNab, 2000; McKechnie & Wolf, 2004; Canterbury, 2002; Weathers, 1979). Comparing small birds from different habitats and with different habits highlights, the ecological significance of BMRs (Rezende et al, 2002) is shown. Take the small-sized birds living in cold environments as an example, though feather growth is limited due to body size, they can resist the cold by increasing heat production (Stokkan, 1992; Liknes et al, 2002); birds living in high latitude temperate zones remain active in winter, mainly through behavioral, formal and physiology mechanical changes (Corp et al, 1997); and birds retain hypothermia in tropical areas (Weathers, 1997).

Mrs Hume's Pheasant (*Syrnaticus humiae*) and Elliot's Pheasant (*Syrnaticus ellioti*) are threatened *Syrnaticus*, *Phasianidae*, *Galliformes* species (Baillie et al, 2004), within Cenwanglaoshan Nature Reserve in China, they are National level protected animals (Zhang et al, 2003). In China, Mrs Hume's Pheasant is only found in Yunnan and Guangxi provinces, but are also found in Northeast India, Northwest Thailand, and the west, north and east Burma. It is a typical species for the southwest subregion mountain areas of the Oriental Realm (Liu et al, 2008). Mrs Hume's Pheasant mainly inhabit broad-leaved forest at an altitude of 780–1800 m,

mixed coniferous broad-leaved forest, scrub woodland, grassland and forest edge areas. It is omnivorous, mainly eating acorns, berries, seeds, roots, leaves, buds and other plant food. It also eats insects and other animal-based food, and occasionally targets cultivated crops at the forest edge (Mackinnon et al, 2000). Elliot's Pheasant, a species peculiar to China, is distributed in Zhejiang, Anhui, Fujian, Jiangxi, Hubei, Hunan, Guangdong, Guangxi, and Guizhou provinces. It is a typical species of eastern hilly subregion in Central China of the Oriental Realm (Shi & Zheng, 1997). Elliot's Pheasant mainly inhabit rugged mountains and the jungle of valleys at an altitude of 200–1500 m, more commonly in mixed coniferous broad-leaved forests. It can also be found in dense bamboo and understory. It is omnivorous, mainly eating plant leaves, stems, buds, flowers, fruits, seeds and other plant food crops, although it also eats insects and other animal-based food (Mackinnon et al, 2000). While limited work has been done on habitat selection and artificial propagation of the two species, no research has been conducted on their energy metabolism. The purpose of this study was to measure the BMR of the two endangered species and research their adaptability to the warm wet climate of Southeast and Southwest China.

1 Materials and Methods

1.1 Animals

Six Mrs Hume's Pheasants (3 males, 3 females) and 6 Elliot's Pheasants (3 males, 3 females) hatched in May 2010 were housed at the Biological Park of Guangxi Normal University. The birds were kept in a closed aviary (95.0 cm × 45.0 cm × 45.0 cm) where the temperature was maintained at approximately 38°C in the first two weeks of their life, and at approximately 35°C in the following two weeks. After one month of age, the birds spent most of the day in open aviaries (5.4 m×2.8 m×1.9 m), which allowed free movement and feeding (food and water supplied *adlibitum*). The experiments were carried out in July 2010 when the birds were 80 days old, the mean body mass of Mrs Hume's Pheasant and Elliot's Pheasant were (398.83±22.93) g and (388.25±14.58) g, respectively.

1.2 Metabolic trials

Oxygen consumption was measured using a closed circuit respirometer (Górecki, 1975). Temperatures in a water bath inside the animal chambers were measured and maintained at a constant level (to ± 0.5 °C). Volume

of the metabolic chamber was 5.8 L. Oxygen consumption rates were measured over a temperature range of 5 – 35 °C, with each trial conducted 45 min after the animals had been in the metabolic chamber for 1 h to stabilize its environment. Food was removed 15 h before each test to minimize the heat increment of feeding and animals were weighed to the nearest ± 0.1 g. Both H₂O and CO₂ were absorbed by silica gel and NaOH. Recording of oxygen consumption due to animal activity in the chamber were discarded when computing the metabolic rate of each individual. All measurements were made daily between 8:00 and 15:00. The metabolic rates (MR) of birds were measured in the rest phase under natural light conditions. The birds were wrapped with gauze to restrict their activities. Reading interval of O₂ consumption was 5 min. Two consecutive, stable and minimum recording were used to calculate metabolic rates as mL O₂/(g·h). Body temperatures (T_b) of all individuals were recorded before and after each measurement, and T_b was measured with a digital thermometer (Beijing Normal University Instruments Co.) in the cloaca at a depth of 1.5 cm. Body mass was measured before and after the experiments.

1.3 Thermal conductance

Over thermal conductance (C , mL O₂/g·h·°C) was calculated at temperature below the thermal neutral zone using the formula as:

$$C = MR / (T_b - T_a)$$

Where MR is metabolic rate (mL O₂/g·h), T_a is ambient temperature (°C), T_b is body temperature (°C). This formula was suggested by Aschoff (1981) for calculating conductance at any given T_a.

Aschoff & Pohl (1970) reviewed the BMRs of bird species, and obtained the allometric equations for birds. Expectation ration of BMR and C predicted by the appropriate equation of Aschoff & Pohl (1970) and Aschoff (1981), respectively, uses the following formulas:

$$BMR = 0.0317W^{0.726}, (W = g, RMR = \text{cal} \cdot \text{h}^{-1})$$

$$C = 0.576W^{0.461}, (W = g, C = \text{mL O}_2/\text{g} \cdot \text{h} \cdot ^\circ\text{C})$$

1.4 Statistics

Data were analyzed using the SPSS11.5 statistical package. Differences between temperature treatments were determined by repeated measures ANOVA and $P < 0.05$ is taken to be statistically significant. All results were expressed as mean $\pm$ SE, and linear regression analysis was used to analyze the relationship between energetic parameters and T_a.

2 Results

2.1 Mrs Hume's Pheasant

Mean T_b of Mrs Hume's Pheasant ranged from a mean of (40.6 $\pm$ 0.07) °C at 24.5 °C to (41.4 $\pm$ 0.11) °C at 35 °C. The T_b of Mrs Hume's Pheasant remained almost constant from 5 to 35 °C T_as, with a mean value of (40.47 $\pm$ 0.64) °C (Fig. 1a).

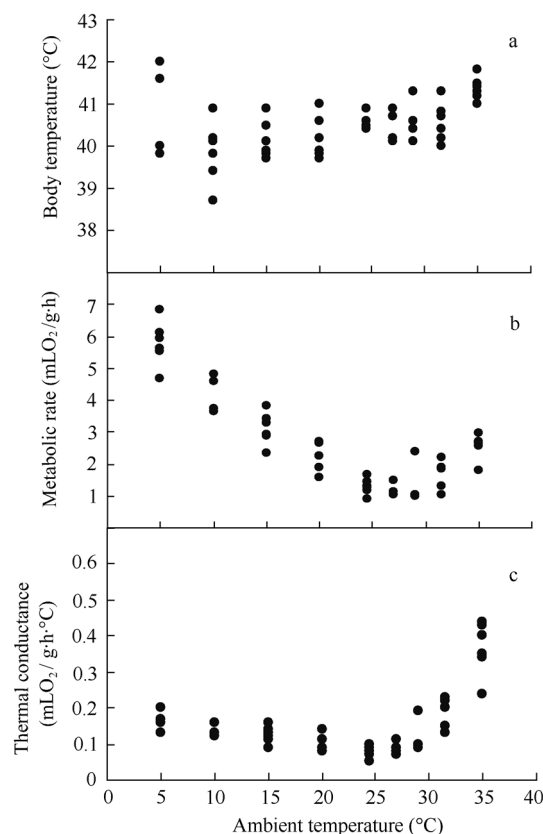


Fig. 1 Changes in body temperature(a), metabolic rate(b) and thermal conductance(c) with ambient temperature in Mrs Hume's Pheasant

There was no significant difference for metabolic rates between 24.5 °C and 31.6 °C (Fig. 1b). The thermal neutral zone (TNZ) was from 24.5 °C to 31.6 °C. Mean BMR was (1.36 $\pm$ 0.84) mL O₂/(g·h) ($n = 24$). Metabolic rates between 20 °C and 24.5 °C showed a significant difference ($t = 4.148$, $df = 28$, $P = 0.000 < 0.0001$), with the difference between 31.6 °C and 35 °C also significant ($t = 6.473$, $df = 28$, $P = 0.000 < 0.0001$). The metabolism rate was variable at temperatures below 24.5 °C and dependent on T_a.

For T_as below 24.5 °C,

$$MR[\text{mL O}_2/(\text{g} \cdot \text{h})] = 6.66 (\pm 0.23) - 0.23 (\pm 0.01) T_a$$

$$(R^2 = 0.904, P = 0.000 < 0.0001)$$

For T_as below 31.6 °C,

$$MR[mLO_2/(g \cdot h)] = -32.69 (\pm 8.64) + 0.85 (\pm 0.21) T_a$$

$$(R^2 = 0.787, P = 0.004 < 0.05)$$

Above 31.6 °C, the metabolic rate increased and attained (2.57±0.16) mLO₂/(g·h) at T_a of 35 °C (Fig. 1b).

Thermal conductance (C) was calculated as (0.12±0.01) mLO₂/(g·h·°C) which was 119% of the predicted value by Aschoff (1981). Within and above the TNZ, C increased significantly with T_a, and reached to (0.37±0.03) mLO₂/(g·h·°C) at 35 °C (Fig. 1c).

2.2 Elliot's Pheasant

Elliot's Pheasant maintained stable T_bs within T_a range of 5 – 35 °C, at which the mean T_b was (40.36±0.10) °C (Fig. 2a).

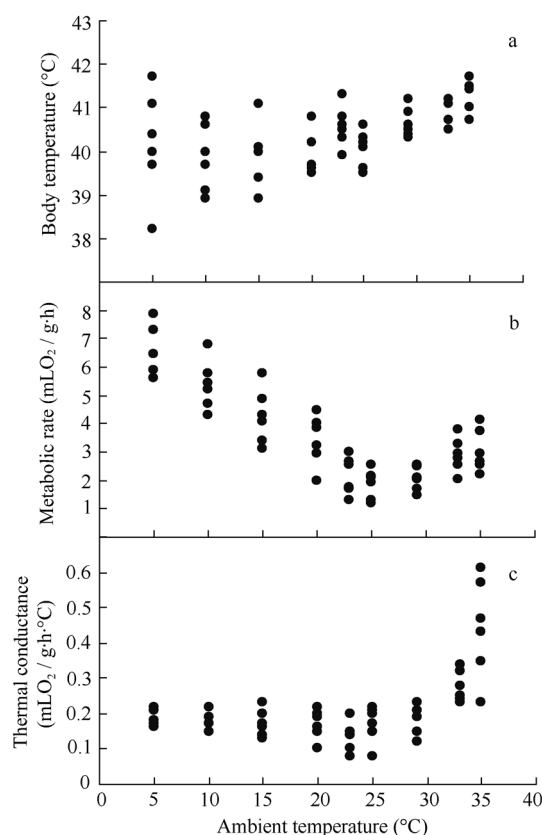


Fig. 2 Changes in body temperature(a), metabolic rate(b) and thermal conductance(c) with ambient temperature in Elliot's Pheasant

There was no significant difference for metabolic rates between 23 and 29.2 °C (Fig. 2b). The thermal neutral zone (TNZ) was from 23 to 29.2 °C. Mean BMR was (2.03±0.12) mLO₂/(g·h) (*n* = 18). Metabolic rates between 20 and 23 °C showed a significant difference (*t* = 4.690, *df* = 22, *P* = 0.000 < 0.0001), with the difference between 29.2 °C and 33 °C also significant (*t* = 3.407, *df*

= 22, *P* = 0.03 < 0.05). Rate of metabolism was variable at temperature below 23 °C and dependent on T_a.

For T_as below 23 °C,

$$MR[mLO_2/(g \cdot h)] = 7.67 (\pm 0.37) - 0.23 (\pm 0.02) T_a$$

$$(R^2 = 0.773, P = 0.000 < 0.0001)$$

For T_as above 29.2 °C,

$$MR[mLO_2/(g \cdot h)] = -33.98 (\pm 7.55) + 0.89 (\pm 0.43) T_a$$

$$(R^2 = 0.550, P = 0.040 < 0.05)$$

Above 29.2 °C, the metabolic rate increased and attained (3.03±0.30) mLO₂/(g·h) at T_a of 35 °C (Fig. 2b).

Thermal conductance (C) was calculated as (0.17±0.01) mLO₂/(g·h·°C), which was 124% of the predicted value by Aschoff (1981). Within and above the TNZ, C increased significantly with T_a, and reached to (0.44±0.06) mLO₂/(g·h·°C) at 35 °C (Fig. 2c).

3 Discussion

3.1 Body temperature

The samples collected in this experiment were relatively small. According to Zhao (2009), the body temperature of Mrs Hume's Pheasant and Elliot's Pheasant nestlings changes with ages. Specifically at 60 days of age the body temperature of the two nestlings fluctuates, while after 60 days of age body temperature stabilizes close to the adult level. This shows that the ability of chemical thermoregulation of Mrs Hume's Pheasant and Elliot's Pheasant is developed to stability level after being hatched for a certain age, usually about 60 days, which is consistent with previous studies on *Tragopan caboti* (Li et al, 1993). Therefore, we measured the metabolites of 80-day-old Mrs Hume's Pheasant and Elliot's Pheasant.

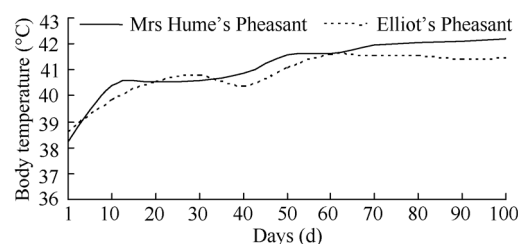


Fig. 3 Changes in body temperature with age in nestling of Mrs Hume's Pheasant and Elliot's Pheasant

Compared with mammals, birds have relatively high T_bs, due to higher energy metabolism needed for bird flight (Prinzinger et al, 1991). Birds can usually maintain body temperature at 40 – 42 °C, and in the TNZ, most birds have a T_b of 38.4 °C. In this study, the T_bs of Mrs Hume's Pheasant (40.47 °C) and Elliot's Pheasant (40.36

°C) were higher than *Crossoptilon mantchuricum* (38.7 °C) and *Lyruruste trix baikallensis* (39.5 °C)(Jia et al, 2003; Zhang et al, 2001), similar to *Coturnix coturnix* (41.5 °C) and *Acridotheres cristatellus* (41.4 °C)(Wang & Zhang, 1986; Lin et al, 2010), but lower than *Erythrura gouldiae* (42.7 °C)(Burton & Weathers, 2003). This has great adaptive significance because the high T_b increases the temperature difference between the body and their environments and increases the ability to dissipate heat in summer (McNab, 2000).

3.2 Basal metabolic rate (BMR)

Many factors affect basal metabolism in birds, such as body mass, climate condition, food habits, season, activity and feeding habits (AL-Mansour, 2004; Weathers, 1979; Liknes et al, 2002; McKechnie & Wolf, 2004; McNab, 1988). In this study, the BMR of Mrs Hume's Pheasant and Elliot's Pheasant were 77% and 86% of the expected value from Ashoff & Pohl (1970), respectively (Tab. 1). The BMRs of Mrs Hume's Pheasant and Elliot's Pheasant were lower than *Prunella rubeculoides* (115%)(Deng & Zhang, 1990), *Prunella montanella* (168%)(Liu et al, 2004a), and *Fringilla montifringilla* (135%)(Liu et al, 2004b); but close to *Erythrura gouldiae* (81%)(Burton & Weathers, 2003), *Estrida melpoda* and *Chloebea gouldiae* (82% and 80% respectively)(Marschall & Prinzinger, 1991), and *Pycnonotus sinensis* and *Sturnus sericeus* (79% and 90% respectively) (Zhang et al, 2006). *Prunella rubeculoides* live in the Qinghai-Tibet Plateau, which experience an average summer temperature of 8.7 °C; *Prunella montanella* and *Fringillamontif ringilla* breed in Siberia and other northern regions, whose heat regulation has obvious high altitudes and cold animals metabolic characteristics. *Erythrura gouldiae* lives in California and other hot and humid regions, where the average winter temperature is 24.4 °C; *Estrida melpoda* and *Chloebea gouldiae* live in the humid tropical environment; *Pycnonotus sinensis* and *Sturnus sericeus* live mainly in the tropical south and southern subtropical monsoon zone of China, and exhibit energy metabolism characteristics typical of tropical birds. The lower BMR of tropical birds is an adaptation to heat stress and water maintenance (Williams & Tieleman, 2000; Tieleman et al, 2002). The BMRs of Mrs Hume's Pheasant (77%) were lower than Elliot's Pheasant (86%), which may relate to the geographical and latitudinal distribution of the two birds as generally a 1°C increase with latitude causes a 1% higher average metabolic rate (Zhang et al,

2001). Mrs Hume's Pheasant and Elliot's Pheasant show characteristics of southern humid zone animals, with their lower metabolic levels a strategy for adapting to the environment. In addition, these two different experimental birds were able to maintain constant body temperatures, that is, when the ambient temperature increased, the body temperature did not increase. To maintain a constant body temperature in a high-temperature environment is one reason why the metabolic rate was relatively low (Rozman et al, 2003; Schleucher, 2002).

Tab. 1 Parameters of energetics in Mrs Hume's Pheasant and Elliot's Pheasant

	Mrs Hume's Pheasant Elliot's Pheasant	
Sample size	6	6
Body mass (g)	398.83±22.93	388.25±14.58
Body temperature (°C)	40.47±0.64	40.36±0.10
a (±SE)	6.66 (±0.23)	7.67 (±0.37)
b (±SE)	-0.23 (±0.01)	-0.23 (±0.02)
r^2	0.904	0.773
P	$P < 0.0001$	$P < 0.0001$
Basal metabolic rate (BMR) [mLO ₂ /(g·h)]	1.36±0.84	2.03±0.12
Expectation ratio of BMR (% pred.)	77	86
Thermal neutral zone (°C)	24.5 – 31.6	23 – 29.2
Lower critical temperature (°C)	24.5	23
Upper critical temperature (°C)	31.6	29.2
Thermal conductance [mLO ₂ /(g·h·°C)]	0.12±0.01	0.17±0.01
Expectation ration of C (% pred.)	119	121

r is the correlation coefficient of regression between metabolic rates (MR) and ambient temperatures (T_a): $MR = a + bT_a$.

Expectation ration of BMR and C predicted by the appropriate equation of Aschoff & Pohl (1970) and Aschoff (1981), respectively, with the formula: $BMR = 0.0317W^{0.726}$, ($W = g$, $RMR = cal \cdot h^{-1}$), $C = 0.576W^{0.461}$, ($W = g$, $C = mL O_2 / g \cdot h \cdot ^\circ C$), % predicted = (observed / predicted) × 100%.

3.3 Thermal neutral zone

The thermal neutral zone (TNZ) is defined as the range of temperatures where production of surplus heat is sufficient to compensate for heat loss, without regulatory changes in metabolic heat production or evaporative heat loss (McNamara et al, 2004). In the TNZ, metabolic rate is independent of T_a and animals can regulate temperature by controlling heat loss instead of metabolic heat production and evaporative heat regulation (Schmidt-Nielsen, 1997). This study showed that the TNZ for Mrs Hume's Pheasant was 24.5 – 31.6 °C and for Elliot's Pheasant was 23.0 – 29.2 °C (Tab. 1). The lower critical temperatures of both these species were

higher than *Crossoptilon mantchuricum* (20 °C)(Jia et al, 2003), *Lyruruste trix baikallensis* (20 °C)(Zhang et al, 2001), *Bombycilla garrulus* and *Emberiza spodocephala* (18 °C and 20 °C respectively)(Li et al, 2005); and similar to *Coturnix coturnix* (25 °C)(Wang & Zhang, 1986), but were lower than *Erythrura gouldiae* (31.7 °C)(Burton & Weathers, 2003), and *Alaemon alaudipes* (32.7 °C) (Tieleman et al, 2002). A birds' high thermal conductance and high temperature can increase both lower and the upper critical temperatures, thus reducing evaporative water loss and reduce energy consumption (Burton & Weathers, 2003). Both Mrs Hume's Pheasant and Elliot's Pheasant had high thermal conductivity and narrow TNZ, which is conducive to the protection of water evaporation and loss and it is an adaptive characteristics to help survive in hot and humid environments.

3.4 Thermal conductance

Overall conductance depends on body weight because of the size dependent changes in the ratio of surface-volume, and the dependence of plumage thickness on size (Aschoff, 1981). In the present study, conductance of Mrs Hume's Pheasant and Elliot's Pheasant were (0.12±0.01) mL O₂/(g·h·°C) and (0.17±0.01) mL O₂/

(g·h·°C) (Tab. 1), which were 119% and 124% of the expected (Aschoff, 1981) values respectively. As the birds were 80 days old in the experiment and were still in the long feathers period, insulation was relatively poor, and therefore heat dissipation and thermal conductivity were relatively high. In addition, thermal conductivity (C) of birds in tropical areas is relatively high but is relatively low for bird in cold regions (Weathers, 1997). For Mrs Hume's Pheasant and Elliot's Pheasant, the high C observed in summer is adaptation to the hot environment as it is conducive for high heat dissipation to avoid overheating.

In short, the ecological characteristics of Mrs Hume's Pheasant and Elliot's Pheasant are in accordance with the metabolic characteristics of southern birds, that is higher body temperature, lower metabolic rate, and higher thermal conductivity. They can better adapt to hot and humid environments through good physical and chemical regulation.

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