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Research

Metabolic Rate and Oxygen Saturation of Fruit Bats (*Cynopterus titthaecheilus* & *Cynopterus brachyotis*)

Anisa Rahma[1*], Desrayni Hanadhita, Hera Maheshwari[2], Aryani Sismin Satyaningtijas[2], Srihadi Agungpriyono[3]

[1]sub-Division of Veterinary Pharmacy, School of Veterinary Medicine and Biomedical Sciences, IPB University, Bogor 16680, Indonesia
[2]Division of Physiology, School of Veterinary Medicine and Biomedical Sciences, IPB University, Bogor 16680, Indonesia
[3]Division of Anatomy, Histology, and Embryology, School of Veterinary Medicine and Biomedical Sciences, IPB University, Bogor 16680, Indonesia
* Corresponding author: drh_anisa_rahma91@apps.ipb.ac.id
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ABSTRACT

Metabolic rate and oxygen saturation are crucial factors in understanding the physiology of fruit bats (*Cynopterus titthaecheilus* and *Cynopterus brachyotis*). This study aims to evaluate the resting metabolic rate and oxygen saturation in bats and their relationship to flight physiology. A total of 32 bats were categorized based on species, sex, and age. Metabolic rate was measured using a metabolic chamber method, while oxygen saturation was monitored using a patient monitoring system. The results showed that bat metabolism is influenced by various factors, including age and sex, without a significant correlation with body mass. Adult female bats exhibited highly fluctuating metabolic rates, possibly due to hormonal factors and increased energy demands during lactation. Additionally, *C. titthaecheilus* had an oxygen saturation of 94%±2.00 for males and 94%±1.73 for females, whereas *C. brachyotis* showed 98%±0.00 in males and 87%±4.16 in females. The high oxygen saturation in bats indicates an efficient oxygen transport system that supports their high metabolic activity during flight. This study provides insights into the physiological strategies of bats in maintaining high metabolism and oxygenation capacity, which are relevant to their ecology and overall health.
***Keywords**: Cynopterus titthaecheilus*, *Cynopterus brachyotis*, metabolic rate, oxygen saturation, bat physiology

ABSTRAK

Laju metabolisme dan saturasi oksigen merupakan faktor penting dalam memahami fisiologi kelelawar pemakan buah (*Cynopterus titthaecheilus* dan *Cynopterus brachyotis*). Penelitian ini bertujuan untuk mengevaluasi laju metabolisme istirahat dan saturasi oksigen pada kelelawar, serta hubungannya dengan fisiologi penerbangan. Sebanyak 32 ekor kelelawar dikategorikan berdasarkan spesies, jenis kelamin, dan usia. Laju metabolisme diukur menggunakan metode metabolor chamber, sedangkan saturasi oksigen dipantau menggunakan pasien monitoring. Hasil menunjukkan bahwa laju metabolisme kelelawar dipengaruhi oleh berbagai faktor, termasuk usia dan jenis kelamin, tanpa korelasi yang signifikan dengan massa tubuh. Kelelawar betina dewasa memiliki fluktuasi metabolisme yang tinggi, kemungkinan karena faktor hormonal dan kebutuhan energi selama menyusui. Selain itu, *C. titthaecheilus* memiliki saturasi oksigen 94%±2.00 untuk jantan dan 94%±1.73 untuk betina, sementara *C. brachyotis* menunjukkan nilai 98%±0.00 pada jantan dan 87%±4.16 pada betina. Tingginya saturasi oksigen pada kelelawar menunjukkan efisiensi sistem transportasi oksigen yang mendukung aktivitas metabolisme tinggi selama penerbangan. Hasil penelitian ini memberikan wawasan tentang strategi fisiologis kelelawar dalam mempertahankan metabolisme dan kapasitas oksigenasi yang tinggi, yang relevan dengan ekologi dan kesehatan hewan.
***Kata kunci:** Cynopterus titthaecheilus*, *Cynopterus brachyotis*, laju metabolisme, saturasi oksigen, fisiologi kelelawar

INTRODUCTION

Metabolism and oxygen saturation are fundamental physiological aspects in living organisms. One of the main factors influencing the metabolic rate is the organism's energy requirement, which increases during active states compared to resting conditions (Nava & Raja, 2019). As energy demands rise, the metabolic rate accelerates accordingly. Among the most energy-demanding activities in animals is flight (Butler, 2016).

Bats are the only mammals capable of powered flight, representing one of the most radical evolutionary adaptations in mammals. This adaptation has resulted in unique structural features of the bat heart (Rahma et al., 2020; Rahma et al., 2021) and profound physiological modifications that support their ability to sustain flight, including alterations in metabolism (Shen et al., 2010).

Recent research on the energy requirements of bats during flight has gained growing attention due to its relevance to their role as potential reservoirs of infectious viruses. The capacity of bats to cover long distances during flight increases their geographical range, thereby enhancing the potential for disease transmission across regions.

In this context, assessing the metabolic rate of resting bats, also known as the resting metabolic rate (RMR), becomes an important parameter for understanding their baseline physiological state. The metabolic rate in mammals represents a key aspect of physiology that determines energy demands for various biological functions. Previous studies have shown that the basal metabolic rate (BMR) of mammals is proportional to body mass raised to the power of two-thirds (White & Seymour, 2003). Information on the metabolic rate of bats can therefore provide valuable insights into their physiological condition when not engaged in flight.

Understanding metabolic rate is closely linked to oxygen saturation and red blood cell characteristics. Oxygen saturation reflects the proportion of oxygen bound to hemoglobin (Hafen & Sharma, 2019). A higher oxygen saturation value indicates a greater oxygen-binding capacity of hemoglobin. Previous hematological studies have reported that bats possess high hemoglobin concentrations and red blood cell counts (Rahma et al., 2017), both of which play a critical role in meeting oxygen demands during flight. However, hematological parameters alone may not fully explain oxygen transport efficiency in flying bats, as oxygen binding and release are determined not only by hemoglobin quantity but also by its capacity to maintain oxygen saturation during intense activity.

The integration of oxygen saturation and hematological data provides a comprehensive approach to understanding the physiological adaptations that enable bats to fulfill their exceptional energetic demands as flying mammals. Therefore, this study aimed to evaluate the metabolic rate and oxygen saturation profile of bats as fundamental indicators of their physiological adaptation for flight.

MATERIALS AND METHOD

Time and Place of Research

The research was conducted from April 2018 to November 2018 at the Anatomy Laboratory, Division of Anatomy, Histology and Embryology; Physiology Laboratory, Division of Physiology; and Surgical Laboratory, Division of Surgery and Radiology, School of Veterinary Medicine and Bio-medicine, IPB. Research procedures were carried out following the advice of the animal ethics commission of the research and community service institution (LPPM), IPB University in 2017 (number 75-2017 IPB).

Materials and Tools

The bats used in this study consisted of adult *Cynopterus titthaecheilus* (n = 13), juvenile *C. titthaecheilus* (n = 8), adult *Cynopterus brachyotis* (n = 9), and juvenile *C. brachyotis* (n = 2). The equipment used in this study included a stopwatch, U-tube manometer, 20 mL syringe, metabolic chamber, and patient monitor (IP-4050, Purescope).

Research Procedure

Measurement of metabolic rate was conducted after the bats were acclimatized for 24 hours. The metabolic rate was measured while the bats were in a conscious state (without the use of anesthetics). Prior to use, the metabolic chamber was tested to ensure there was no leakage. The chamber was tightly sealed in an empty condition, and air was injected using a syringe to create slight positive pressure inside the chamber. The movement of the liquid column in the U-tube manometer was continuously observed for 5–10 minutes. A stable and unchanged liquid level indicated that the chamber was airtight, whereas a consistent rise or fall of the liquid level suggested the presence of leakage at the joints or the chamber cover. An additional step was performed by injecting a known volume of air (e.g., 50 mL) to test the response of the liquid column in the U-tube, which also served as a calibration factor for the apparatus.

The bat was placed inside the chamber, after confirming that the metabolic chamber was free of leaks. The air within the chamber was withdrawn using a syringe, after which the chamber was sealed again to ensure airtightness. The withdrawn air was then re-injected into the chamber, resulting in a rise in the liquid level on one side of the U-tube manometer. Observations were made to determine the time required for the liquid level to return to equilibrium. The parameters obtained during this observation included body mass (Mt), oxygen consumption volume within a day (V1), ambient air temperature (T1), ambient air pressure (P1), air temperature at standard temperature and pressure (T2), and air pressure at standard temperature and pressure (P2). These parameters were used to calculate the total oxygen consumption of the bat within a 24-hour period.

For oxygen saturation measurement, the bats were anesthetized to facilitate handling and to minimize movement. The anesthesia served as a restraint method. During anesthesia, the bats' physiological condition was monitored using a patient monitor, and their oxygen saturation (SpO_2) values were recorded. Measurements of both oxygen saturation and metabolic rate were conducted in triplicate for each individual bat. The calculation of the metabolic rate using the metabolic chamber was carried out according to the following procedure:

1. *Oxygen consumption per day at standard temperature and pressure (STP), V_2 (L):*

$$\frac{T2 \times P1}{T1 \times P2} \times V1$$

2. *Oxygen consumption per hour (mL):*

$$\frac{V2}{24 \text{ hours}} \times 1000$$

RESULTS

Metabolic Rate

This study revealed variations in the metabolic rate of fruit bats (Cynopterus titthaecheilus and Cynopterus brachyotis), which were also influenced by sex, age, and individual body mass, as presented in Table 1. Based on Table 1, both C. titthaecheilus and C. brachyotis exhibited interindividual and intergroup variations in metabolic rate values. These values were not directly compared between species because the two species have different adult body sizes. C. brachyotis is a smaller fruit bat species compared to C. titthaecheilus. Therefore, the interpretation of metabolic rate values is more appropriately conducted within the same species, considering age and sex as the main distinguishing factors.

In *C. titthaecheilus*, the average metabolic rate ranged from 197.95 ± 83.58 cm^3 O_2 h^{-1} in juvenile males to 238.07 ± 77.90 cm^3 O_2 h^{-1} in adult males. In females, the values ranged from 216.75 ± 58.89 cm^3 O_2 h^{-1} in adult females to 257.59 ± 80.31 cm^3 O_2 h^{-1} in juvenile females. In *C. brachyotis*, the highest metabolic rate was recorded in adult males, with a value of 259.22 ± 32.85 cm^3 O_2 h^{-1}, while the lowest value was found in juvenile females (109.72 ± 9.43 cm^3 O_2 h^{-1}). Adult females exhibited a metabolic rate of 170.31 ± 59.19 cm^3 O_2 h^{-1}. These findings indicate noticeable variations in metabolic rate among sex and age groups; however, all observed values remained within the normal physiological range for fruit bats.

The comparison between metabolic rate and body mass for each species is presented in Figure 1 and Figure 2. Figure 1 shows a tendency for an increase in metabolic rate with increasing body mass in *Cynopterus titthaecheilus.* However, considerable variation was observed among individuals, as indicated by the large standard deviation values. This variation suggests the influence of individual physiological factors, such as activity level or hormonal status differences.

Table 1. Metabolic rate of fruit bats (Cynopterus sp.)

Species	Sex	Age	Body Mass (g)	Metabolic rate (cm^3O_2/hour)
C. titthaecheilus	Male	Adult	68.26	238.07±77.90
		Juvenile	51.89	197.95±83.58
	Female	Adult	73.86	216.75±58.89
		Juvenile	57.40	257.59±80.31
C. brachyotis	Male	Adult	29.00	259.22±32.85
		Juvenile	-	-
	Female	Adult	36.79	170.31±59.19
		Juvenile	32.75	109.72±9.43

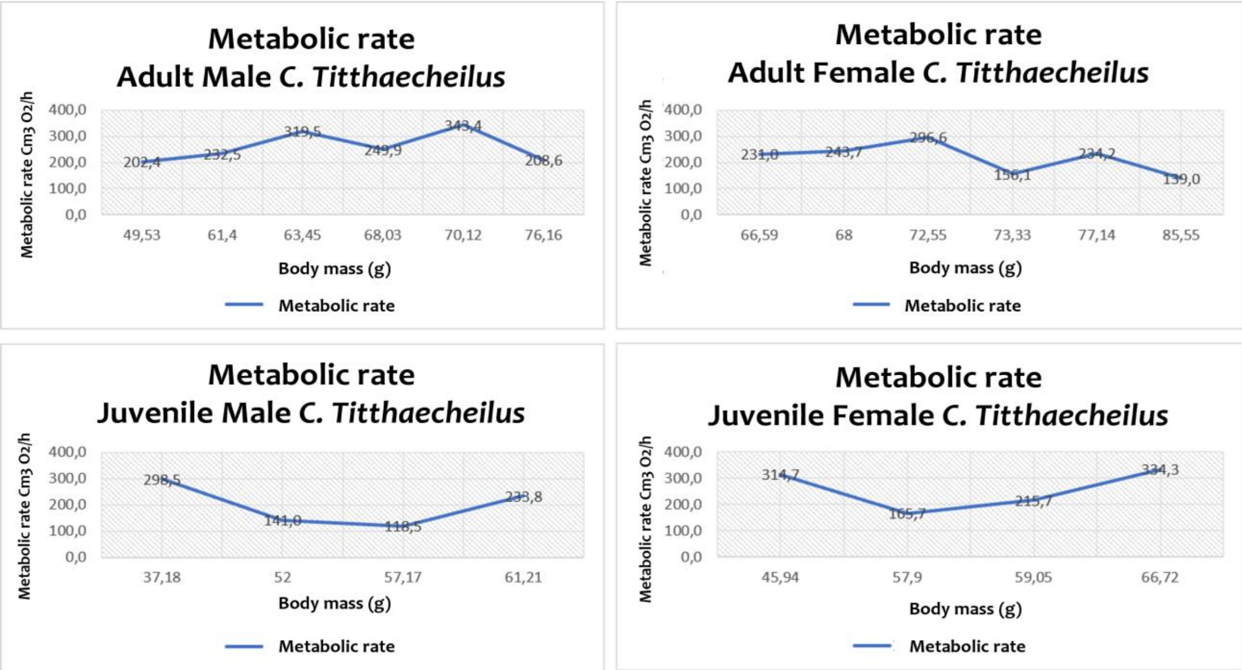
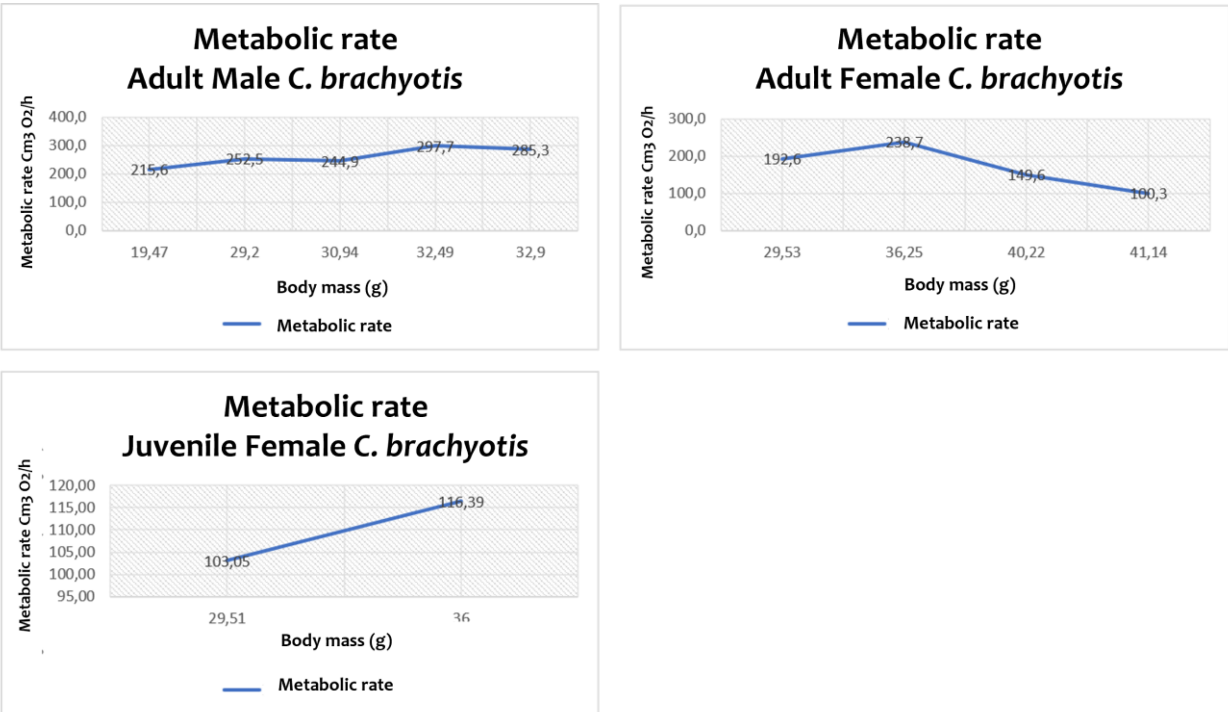


Figure 1 Metabolic rate correlation with the body mass in *C. titthaecheilus*



Figue 2. Metabolic rate correlation with the body mass in *C. brachyotis*

The analysis of metabolic rate in *Cynopterus brachyotis* presented in Figure 2 showed a different trend. *C. brachyotis* exhibited a tendency for lower metabolic rates in individuals with higher body mass, particularly among females. This pattern was evident from the lower metabolic rate observed in juvenile females compared to adult females, despite their lighter body mass. Such differences indicate that factors other than body mass may contribute to variations in metabolic rate, such as differences in metabolic age or physiological maturity level.

Linear regression analysis between body mass and metabolic rate showed contrasting patterns in the two bat species. In *Cynopterus titthaecheilus*, the relationship was weak ($R^2 = 0.02$; $y = 206.93 + 0.33x$), indicating that body mass explained only a small portion of metabolic variation, while other factors such as age or physiological status likely had greater effects. In *Cynopterus brachyotis*, a moderate negative correlation ($R^2 = 0.33$; $y = 543.48 - 11.07x$) was found, suggesting that higher body mass was associated with lower metabolic rate. These contrasting trends reflect interspecific differences in metabolic physiology and adaptive energy strategies.

Based on sex comparison, male bats generally exhibited higher metabolic rates than females in both species, particularly in the adult phase. In *Cynopterus titthaecheilus*, adult males showed a metabolic rate of 238.07 ± 77.90 $cm^3\ O_2\ h^{-1}$, which was higher than that of adult females at 216.75 ± 58.89 $cm^3\ O_2\ h^{-1}$. Similarly, in *Cynopterus brachyotis*, adult males exhibited a metabolic rate of 259.22 ± 32.85 $cm^3\ O_2\ h^{-1}$, considerably higher than that of adult females (170.31 ± 59.19 $cm^3\ O_2\ h^{-1}$).

Descriptive analysis revealed a pattern indicating that juvenile individuals exhibited greater variation in metabolic rate compared to adults, both in *Cynopterus titthaecheilus* and *Cynopterus brachyotis.* This finding was reflected by relatively higher standard deviation values in the juvenile groups. In *C. titthaecheilus,* the metabolic rate of juvenile males (197.95 ± 83.58 $cm^3\ O_2\ h^{-1}$) and juvenile females (257.59 ± 80.31 $cm^3\ O_2\ h^{-1}$) showed a wider range compared to the adult groups. In *C. brachyotis,* the metabolic rate of juvenile females (109.72 ± 9.43 $cm^3\ O_2\ h^{-1}$) appeared more consistent but was relatively lower compared to other groups.

The overall observations revealed that the metabolic rate of fruit bats is influenced by a combination of factors, including species, sex, age, and individual body mass. Although body mass contributes to determining oxygen requirements, the results indicate that both interspecific and interindividual variations remain significant. The distribution pattern of metabolic rate values provides a crucial foundation for understanding the physiological characteristics of fruit bats and may serve as a reference for further studies on ecophysiological aspects and metabolic adaptations to tropical environments.

Oxygen Saturation

In this study, bats of the genus *Cynopterus* were anesthetized using a combination of ketamine and xylazine administered via intramuscular injection. This anesthetic combination was selected because it has been proven effective in producing safe, short-term sedation and immobilization in fruit bats while maintaining relatively stable respiratory function during anesthesia. The use of ketamine–xylazine was also considered practical for field applications, requiring minimal equipment compared to inhalation anesthesia.

The oxygen saturation values observed in both species generally remained within the normal physiological range for small mammals, although interspecific and sex-related variations were present. In *Cynopterus titthaecheilus,* the oxygen saturation value recorded in males was 94% ± 2.00, while in females it was 94% ± 1.73 (Table 2). These values indicate a uniform oxygen saturation level between sexes with low individual variation. The low standard deviation suggests that during anesthesia, *C. titthaecheilus* was able to maintain consistent blood oxygenation stability in both males and females. This uniformity also indicates that the respiratory system of the species functions efficiently in maintaining oxygen diffusion and stable pulmonary ventilation, even under anesthetic conditions.

In *Cynopterus brachyotis*, a greater variation was observed between males and females. The oxygen saturation value in males reached 98% ± 0.00, while in females it was only 87% ± 4.16. The difference in

Table 2. Oxygen saturation of two fruit bat species (Cynopterus sp.) under anesthesia

Species	**Sex**	
	Male	Female
C.titthaecheilus	94%±2.00	94%±1.73
C.brachyotis	98%±0.00	87%±4.16

standard deviation reflects an unequal level of oxygenation stability between the two sexes. In males, no interindividual variation was observed (SD = 0.00), indicating that all male *C. brachyotis* individuals were able to maintain maximal oxygen saturation during anesthesia. In contrast, the larger variation observed in females suggests differences among individuals in their ability to sustain optimal oxygen diffusion. The mean oxygen saturation value of 87% in females also indicates a marked reduction in blood oxygenation compared to other groups. This difference is likely related to variations in physiological condition among individuals. In the present study, one of the female *C. brachyotis* individuals was found to be pregnant, which may have influenced the observed decrease in oxygen saturation.

In comparison, male *Cynopterus brachyotis* exhibited the highest oxygen saturation value (98% ± 0.00), whereas female *C. brachyotis* showed the lowest value (87% ± 4.16). Both male and female *Cynopterus titthaecheilus* displayed uniform oxygen saturation levels (94% ± low SD). This uniformity is likely due to the more consistent physiological condition observed in *C. titthaecheilus* individuals, in contrast to *C. brachyotis*, in which one female was later identified as pregnant.

The high oxygen saturation level observed in male *Cynopterus brachyotis* indicates that this small-bodied species possesses an efficient oxygen diffusion capacity during anesthesia. This condition suggests that the respiratory and circulatory systems in male *C. brachyotis* function optimally to maintain respiratory homeostasis even under anesthetized conditions. In contrast, the lower oxygen saturation values and higher variation observed in female *C. brachyotis* indicate that some individuals experienced a reduction in blood oxygenation, which may have resulted from the pharmacological effects of anesthesia on respiratory frequency or from physiological sensitivity to anesthetic agents.

In *Cynopterus titthaecheilus*, uniform oxygen saturation values between males and females indicate that sex differences had minimal influence on respiratory response during anesthesia. This stability suggests efficient pulmonary and ventilation mechanisms and good respiratory adaptation to physiological changes. SpO_2 levels above 90% in most groups confirm effective oxygenation and adequate tissue oxygen supply. Only female *C. brachyotis* showed slightly lower values (87%), which remain within a tolerable range considering individual physiological variation. Overall, both species maintained sufficient oxygenation efficiency under anesthesia, reflecting stable respiratory performance in fruit bats.

Overall oxygen saturation results indicate that blood oxygen levels during anesthesia remained within a safe range in both bat species, despite variations between sexes and species. *Cynopterus titthaecheilus* showed a more stable and homogeneous oxygenation pattern, whereas *C. brachyotis* exhibited sharper differences, particularly in females. These findings suggest that anesthetic sensitivity and respiratory capacity may differ across species and sexes. Such data are essential for determining appropriate anesthetic dosages and agents for fruit bats in experimental or veterinary medical procedures.

DISCUSSION

Metabolic Rate

Metabolic rate in living organisms is influenced by temperature, body mass, age, activity, sex, and physiological condition (Glazier, 2008). Comparatively, bats generally exhibit a higher basal metabolic rate (BMR) than terrestrial mammals of similar body size, such as rats (*Rattus* spp.) (Selman et al., 2001). This difference is associated with their ability for powered flight, which demands a greater energy requirement and involves physiological adaptations to sustain high levels of aerobic activity.

The other small mammals, such as *Mus musculus* and *Rattus norvegicus*, exhibit lower basal metabolic rates compared to fruit bats. *Mus musculus* with an average body mass of approximately 25 g has a basal metabolic rate (BMR) of about 1.16 mL O_2 g^{-1} h^{-1} (Mathias& Santos, 2004), while *Rattus norvegicus* shows a BMR of around 0.70 mL O_2 g^{-1} h^{-1} (Dawson & Hulbert, 1970). Small marsupials such as *Antechinus stuartii* and *Sminthopsis crassicaudata* exhibit even lower values, ranging from 0.50 to 0.70 mL O_2 g^{-1} h^{-1} (Geiser, 1988). Small primates like *Microcebus murinus* have a BMR of approximately 1.28 mL O_2 g^{-1} h^{-1} (Perret, 1998). These values remain below the BMR range observed in fruit bats reported in the present study.

Flight in bats requires three to five times more energy than that needed by terrestrial mammals of comparable body mass (Shen et al., 2010). This high energy demand has driven the evolution of the respiratory and metabolic systems in bats to support efficient energy production. Genomic analyses have revealed positive selection on genes involved in oxidative phosphorylation (OXPHOS) pathways, encoded by both mitochondrial and nuclear genomes, thereby enhancing metabolic capacity alongside the evolution of flight ability. These findings indicate that bats have undergone genetic adaptations to optimize the conversion of nutrients into energy (Shen et al., 2010). Furthermore, their nocturnal lifestyle also contributes to the elevated metabolic rate, as endothermic animals active at night must maintain stable body temperatures in environments with relatively lower ambient temperatures.

The relationship between body mass and metabolic rate in both bat species was not statistically significant, although a tendency for increased metabolic rate was observed in individuals with certain body masses. This pattern suggests that other factors, such as age, sex, and species differences, play a more dominant role in influencing metabolic variation. The low coefficient of determination ($R^2 = 0.02$) in *Cynopterus titthaecheilus* indicates that body mass is not the primary determinant of metabolic rate, whereas the moderate negative relationship observed in *C. brachyotis* ($R^2 = 0.33$) reflects a limited effect of body mass on metabolism.

Metabolic variation was also observed between different ages and sexes. Female individuals exhibited a wider range of metabolic rates than males, particularly in the juvenile female groups of *Cynopterus titthaecheilus* and *C. brachyotis.* This variation may be associated with physiological and hormonal differences between sexes. Ayala-Berdon and Medina-Bello (2024) reported that body condition, reflecting energy reserves and tissue composition, is closely related to metabolic rate. In female bats, reproductive phases such as pregnancy, lactation, or post-parturition can significantly increase energy requirements due to placental villi degeneration (Yekti et al., 2017) and milk production (Bionaz et al., 2012). Hormonal fluctuations may also affect mitochondrial enzymatic activity and substrate oxidation rate, resulting in greater metabolic variation compared to males.

Although body mass did not significantly affect metabolic rate, bats maintained high metabolic activity. Even at rest, their energy demand exceeded that of terrestrial mammals of similar size. Genomic analyses revealed that about 23% of bat genes show positive selection and 2% exhibit substantial evolutionary changes, mainly in mitochondrial and energy metabolism pathways (Shen et al., 2010). These findings indicate that metabolic variation in fruit bats is primarily influenced by physiological factors such as age and sex, reflecting evolutionary adaptations to powered flight and nocturnal activity that require high energy efficiency in tropical environments.

Oxygen Saturation

Hemoglobin affinity for oxygen is a determining factor in regulating oxygen release to peripheral tissues. The distribution of oxygen throughout organ systems plays a vital role in maintaining cellular metabolic homeostasis (Vidiastuti et al., 2014). Monitoring SpO_2 values provides essential information regarding the efficiency of the oxygen transport system and can serve as a reference for clinical decision-making in veterinary practice.

Mammals have developed physiological adaptations to maintain optimal oxygen saturation under low pressure. These include enhanced oxygen supply capacity evolved to meet maximal metabolic demands. Studies indicate that oxygen delivery capacity aligns with evolved oxygen demand regardless of body size or temperature (Seibel & Deutsch, 2020). Mammals in hypoxic environments, such as subterranean or high-altitude habitats, have evolved specific mechanisms involving physiological adjustments, gene expression regulation, and genetic mutations that support survival under low-oxygen conditions (Li et al., 2021). Bats represent one of the taxa exhibiting unique adaptations to high oxygen demand. The order *Chiroptera* is characterized by small-sized erythrocytes with high red blood cell density and elevated hemoglobin concentration, enabling them to meet substantial oxygen requirements during flight activity (Rahma et al., 2017).

Bats are known to possess a high basal metabolic rate accompanied by superior oxygen saturation capacity. Oxygen saturation (SpO_2) represents the percentage of oxygenated hemoglobin in the circulating blood and serves as a crucial parameter for evaluating oxygenation status in animals, particularly during medical procedures such as anesthesia. The administration of anesthetic agents, including ketamine and xylazine, has been reported to induce a decrease in SpO_2 values (Noviana et al., 2009). For comparison, SpO_2 values in healthy humans typically range between 96% and 98% (Collins et al., 2015).

Administration of ketamine at low doses generally does not induce respiratory depression, although it may cause an increase in respiratory rate or tachypnea (Arieski et al., 2018). In contrast, xylazine administration is known to cause significant central nervous system depression, manifested as respiratory depression and hypotension. These effects are primarily mediated by the α_2-adrenergic agonist activity of xylazine, which reduces respiratory muscle activity and leads to a decrease in cerebral oxygen levels. Additionally, xylazine may induce peripheral vasodilation, contributing to lowered blood pressure and indirectly resulting in a reduction of CO_2 levels in the circulation. The combination of ketamine and xylazine is commonly applied to minimize the adverse effects produced by each agent individually.

The use of ketamine–xylazine was selected because previous studies have demonstrated its effectiveness in producing short-term sedation and immobilization in bats. Sohayati et al. (2008) reported that the combination of ketamine and xylazine produced a rapid induction time (approximately 80 seconds) and an immobilization duration of around 26 minutes in *Pteropus hypomelanus*, with low mortality and minimal respiratory complications. Similar results were also reported by Heard et al. (2006) in *Pteropus hypomelanus* and by Amari et al. (2022) in *Rousettus aegyptiacus*, where the combination of a dissociative agent (ketamine) and an α_2-agonist (xylazine or medetomidine) produced stable sedation with minimal disruption to cardiovascular and respiratory systems.

The SpO_2 values observed in this study were relatively high for anesthetized animals. Elevated SpO_2 indicates a superior proportion of oxygenated hemoglobin. The high concentrations of hemoglobin and erythrocytes, together with optimal hemoglobin affinity, synergistically enhance the metabolic rate of bats, as oxygen supply capacity positively correlates with energy production.

These findings also suggest a specific physiological adaptation in bats, in which respiratory efficiency and oxygen-binding capacity remain well maintained even under anesthesia, a condition that generally suppresses respiratory function. This condition indicates that bats possess a superior respiratory compensation mechanism compared to non-flying mammals of similar size. Therefore, the high SpO_2 values observed in anesthetized bats can be considered a reflection of physiological efficiency that supports their flight capacity and high aerobic metabolic demand.

This study demonstrates that fruit bats have a higher metabolic rate than mammals of comparable body size, reflecting their substantial energy demands for sustained flight. They are able to maintain high blood oxygen saturation levels, reaching up to 98% under anesthesia, indicating efficient respiratory function and strong hemoglobin oxygen-binding capacity. These findings confirm that enhanced metabolic and respiratory efficiency represent key physiological adaptations supporting flight performance in bats. Further studies with larger sample sizes and non-anesthetized measurements are recommended to better represent the natural physiological mechanisms and adaptive responses of bats to the energetic demands they must meet as the only flying mammals.

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