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Comparative analysis of latitudinal variations in physiological indicators between Rodentia and Chiroptera mammals

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Author contributions

Data analysis, Writing – original draft preparation, Cao LJ; writing – review and editing, Zhu WL. All authors have read and agreed to the published version of the manuscript.

Competing interests

The authors declare no conflicts of interest.

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Abbreviations

BMR, basal metabolic rate; TNZ, thermal neutral zone; COX, cytochrome c oxidase; C, carnivorous; H, phytophagous; O, omnivorous; UTNZ, upper thermal neutral zone; LTNZ, lower thermal neutral zone.

Citation

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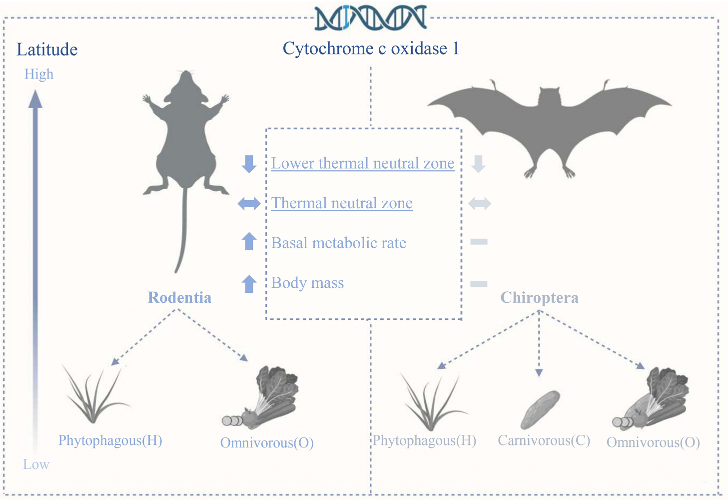
Abstract

Background: The thermogenic characteristics of animals are closely related to species distribution, and basal metabolic rate (BMR) and thermal neutral zone (TNZ) are important components of the thermogenic process in animals. Furthermore, the cytochrome c oxidase 1 (COX1) gene has become a subject of particular interest due to its high degree of sequence conservation, stable evolutionary rate, and rare insertions/deletions. **Method:** The present study selected 29 species of Rodentia and 20 species of Chiroptera. The present study employed the statistical software SPSS (27.0 Chinese version) and Origin (2024 Chinese version) software to conduct correlation analyses on a variety of biological and ecological variables. These variables included body weight, BMR, TNZ, upper thermal neutral zone, lower thermal neutral zone (LTNZ), litter size, and dietary patterns of species from different latitudes. Furthermore, we conducted a series of phylogenetic tree analyses on COX1 protein. **Results:** As the geographic location of a species increases in latitude, there is an observed upward trend in both body mass and BMR of rodent species. Rodentia and Chiroptera species have been observed to exhibit a decrease in LTNZ and an expansion of TNZ. With regard to dietary habits, Rodentia species are predominantly phytophagous or omnivorous. Omnivorous species exhibit a marked tendency to produce larger litters in comparison to their herbivorous counterparts. Chiroptera species exhibit a diverse dietary range, including phytophagous, carnivorous, and omnivorous species. However, no correlation was observed between dietary differences and litter size. Phylogenetic analysis of the COX1 protein subsequently demonstrated that these two species groups share a monophyletic origin. **Conclusion:** The present study suggests that the selected Rodentia and Chiroptera species adapt to high-latitude environments by lowering the LTNZ and widening the TNZ. Furthermore, an upward trend has been observed in the body mass and BMR of high-latitude Rodentia. Phylogenetic analysis of the COX1 protein across various taxonomic groups substantiates the efficacy of this gene for species identification. Integrating physiological phenotypes with COX1 protein molecular evidence, this study provides a reference framework for the multidimensional mechanisms of mammalian latitudinal adaptation.

Keywords: latitude; diet; thermal neutral zone; metabolic rate; cytochrome c oxidase 1 protein



Introduction

The survival of mammals is closely related to their external environment. Variations in latitude are often accompanied by changes in ecological factors, including environmental temperature, photoperiod, and food resources. These variations subsequently influence the growth, development, and reproduction of mammals [1, 2]. As environmental temperatures fluctuate, metabolic plasticity in mammalian physiological adaptation dynamically adjusts energy allocation strategies to cope with environmental challenges [3]. In the domain of energy metabolism research, basal metabolic rate (BMR) serves as a pivotal indicator of animal metabolic levels [4]. It denotes the minimum energy expenditure necessary to sustain life in awake, endothermic subjects under resting conditions [5].The thermal neutral zone (TNZ) is defined as the specific temperature range in which animals maintain their BMR. It has been established as a pivotal physiological indicator of thermal adaptation in endotherms [6, 7]. Furthermore, evidence suggests a correlation between energy expenditure and litter size in Rodentia [8, 9]. Therefore, the investigation of the effects of latitude on mammalian physiological traits, including body mass, average litter size, BMR, and TNZ, is of significant importance.

Rodentia constitute the most species-rich group among mammals, comprising approximately 40% of all mammalian species. Their remarkable adaptability renders them an ideal model for studying ecological and evolutionary mechanisms [10]. The order Rodentia currently encompasses over 2,000 recognized species, distributed across a wide range of habitats, from polar tundras to equatorial rainforests [11, 12]. These animals exhibit significant variations in body size, complex dietary specializations, and diverse reproductive strategies [13–15]. Chiroptera are the only mammals capable of powered flight, with approximately 1,400 species globally distributed from tropical to temperate regions [16]. Their diets include highly specialized niches such as insectivory, frugivory, and hematophagy [17]. Notably, Chiroptera exhibit distinctive reproductive traits, such as small litter sizes and delayed sexual maturity [18]. Due to their high-energy flight metabolism and tightly coupled thermoregulation, Chiroptera serve as an excellent model for studying energy adaptation mechanisms [19]. Rodentia and Chiroptera represent two highly significant mammalian groups, and the study of these taxa can yield invaluable insights into the adaptive traits and survival strategies that have evolved during mammalian evolution.

Luo et al. identified three amino acid variations in the cytochrome c oxidase (COX) gene that may contribute to pika adaptation to cold environments [20]. As the primary site of cellular oxygen consumption, COX is functionally linked to aerobic energy production (in the form of adenosine triphosphate) and BMR [21–23]. The catalytic core of COX consists of three subunits (COX1, COX2, and COX3) encoded by mitochondrial DNA [21]. Among these, the COX1 gene has been the subject of particular interest due to its high degree of sequence conservation, stable evolutionary rates, and infrequent insertions/deletions [24]. This gene has been extensively utilized in evolutionary and functional studies. Consequently, the investigation of species evolution and its relationship with metabolism through the COX1 gene is of particular importance.

The present study concentrates on the adaptive evolution of Rodentia and Chiroptera along latitudinal gradients, with the objective of elucidating the influence of latitude on physiological traits. The analysis will entail the examination of the associations between latitude/dietary habits and key parameters such as body mass, BMR, TNZ, and reproductive strategies. This will be done in order to uncover fundamental patterns of environmental adaptation and survival capacity. Furthermore, comparative analysis of COX1 protein sequences will assess genetic divergence between these two orders during evolution, validating their independent evolutionary trajectories in traditional taxonomy while providing a foundational data set for exploring protein-metabolism interactions.

Materials and methods

Experimental materials

In the present study, key physiological parameters such as geographic range, latitude and longitude coordinates, TNZ, and body mass of small mammals were obtained through a literature search. These parameters were selected based on data completeness and consistency of experimental conditions. The BMRs of the selected species were calculated by Kleiber's law [25, 26]. Kleiber's law states that an animal's BMR is proportional to the 3/4th power of its body weight, with α being a constant. For mammals, the value of α is usually about 3.4 and the formula for basal metabolic rate can be expressed as: $\text{BMR} = \alpha \times M^{0.75}$. The scientific names of the species were then searched using the animal diversity web database (https://animaldiversity.org/) to record information on their dietary habits and predation strategies. The species' dietary habits were classified into three categories: carnivorous (C), phytophagous (H), and omnivorous (O). In addition, all COX1 protein sequences utilized in this study were obtained from the national center for biotechnology information database (https://www.ncbi.nlm.nih.gov/). The comprehensive set of experimental data has been meticulously documented in Table 1 [27–61].

Statistical analysis

The relevant statistical processing and mapping were carried out using SPSS (27.0) and Origin (2024) software, respectively. SPSS (27.0) software was employed for statistical analysis of the TNZ, upper thermal neutral zone (UTNZ), lower thermal neutral zone (LTNZ), BMR, body mass, and litter size of Rodentia and Chiroptera at various latitudes. The distributional characteristics of the data were assessed by means of normality tests and dietary habits. C, H, and O were transformed into dummy variables for quantitative analyses in the statistical model. The application of linear regression analysis was then employed to elucidate potential relationships among these variables. To this end, multiple linear regression models were constructed, with latitude and dietary habits serving as independent variables and TNZ, UTNZ, LTNZ, BMR, body mass, and litter size as dependent variables. Finally, *P*-values ($P < 0.05$ was considered significant) were analyzed to determine whether the correlations between the variables were significant or not, and the strength of the correlations was assessed in conjunction with the correlation coefficients.

The drawing tools in Origin (2024) software were used to create 2Ys Y-Y graphs to show the trends of LTNZ and TNZ for Rodentia and Chiroptera at different latitudes. Chordal plots were used to show the proportion-ality between the different feeding categories of the two major groups; and multifactorial grouped bar charts were used to represent the trend of BMR, LTNZ, UTNZ, TNZ, and litter size of Rodentia and Chiroptera under different feeding conditions. Chiroptera' BMR, LTNZ, UTNZ, TNZ, and litter size under different dietary categories were subsequently analyzed. To further explore the complex association between latitude and BMR, BMR, LTNZ, UTNZ, and TNZ variables, correlation heatmaps were plotted for visual analysis. These heatmaps presented the degree and direction of the correlation between each variable two by two.

COX1 protein evolution tree construction

In order to thoroughly investigate the evolutionary relationship between Rodentia and Chiroptera, the maximum likelihood method was employed to construct the evolutionary tree of the COX1 protein sequence using the MEGA X software. Initially, the COX1 protein sequence was subjected to multiple sequence alignment to ensure the accuracy and completeness of the sequence. The model selection function of MEGA X software was then utilized to ascertain the most suitable evolutionary model for this analysis. A preliminary evolutionary tree was subsequently constructed based on this model using the maximum likelihood method. The reliability of the tree was assessed by performing a Bootstrap self-expansion test, with the number of repetitions set to 1,000 to ensure the credibility of the

Table 1 Parameters related to physiological indicators of Rodentia and Chiroptera

Order	Species	NCBI number	Latitude (°N)	TNZ (°C)	UTNZ (°C)	LTNZ (°C)	Dietary habit	BMR (W)	Body mass (kg)	Litter size (ind)	Reference
Rodentia	*Acomys cahirinus*	> YP007626812	30.03	5.5	32.5	27	H	0.315	0.0420	3	Kronfeld-Schor et al. (2001) [27]
	Chaetodipus hispidus	> ADW62383	27.59	3	33.5	30.5	O	0.280	0.0358	3.5	Wang and Hudson (1970) [28]
	Ctenomys talarum	> AFN25994	–37.46	5	30	25	H	0.676	0.1160	3.5	Busch (1989) [29]
	Cynomys ludovicianus	> AJG02730	47.17	5	35	30	H	3.683	1.1123	3.5	Hamilton and Pfeiffer (1977) [30]
	Dipodomys deserti	> ABO84865	35.46	6.5	35	28.5	H	0.632	0.1060	3.5	Mcnab (1979) [31]
	Dipodomys microps	> ABW83076	36.052	5	32	27	H	0.398	0.0572	3	Breyen et al. (1973) [32]
	Erethizon dorsatum	> AEE10834	61.41	20	20	0	H	15.731	7.7100	1.5	Fournier and Thomas (2012) [33]
	Graomys griseoflavus	> UMB50040	–33.2	8.4	34	25.6	H	0.460	0.0694	3	Caviedes-Vidal et al. (1987) [34]
	Heteromys irroratus	> ABW83101	27.06	3	34	31	H	0.349	0.0481	3	Mcnab (1979) [31]
	Heteromys salvini	> ADZ16785	12.08	3	34	31	O	0.326	0.0438	3	Rogers and Vance (2005) [35]
	Meriones unguiculatus	> QEE83128	46.51	10	40	30	H	0.417	0.0610	3.5	Wang (2000) [36]
	Microtus californicus sanctidiegi	> WNV23453	33.3	7	40	33	H	0.327	0.0440	4.5	Rissman and Johnston (1986) [37]
	Microtus montanus	> YP010554791	46.43	5	31	26	H	0.366	0.0512	5.5	Packard (1968) [38]
	Microtus ochrogaster	> AFD12495	40.35	9	34	25	H	0.345	0.0474	5.5	Wunder et al. (1977) [39]
	Microtus richardsoni	> UYP50609	44.19	11	33.5	22.5	H	0.366	0.0513	5.5	Farlow and James (2005) [40]
	Mus macedonicus	> YP011011194	32.44	5	33	28	O	0.142	0.0145	6	Haim et al. (1999) [41]
	Mus musculus	> AGG11000	42.445	6	33	27	O	0.338	0.0460	6	Buffenstein et al. (1985) [42]
	Ochrotomys nuttalli	> XKT67337	29.15	6.5	36	29.5	H	0.177	0.0195	3.5	Layne and Dolan (1975) [43]
	Octodontomys gliroides	> ADE88004	–42.453	10	35	25	H	0.828	0.1520	3	Arends and McNab (2001) [44]
	Ondatra zibethicus	> AUX81213	40.71	15	30	15	O	3.412	1.0046	6	Fish (1979) [45]
	Onychomys torridus	> ADW62372	32.19	5	35	30	O	0.175	0.0191	3.5	Whitford and Conley (1971) [46]
	Peromyscus californicus	> XKT67376	37.8715	7.5	34.5	27	H	0.357	0.0496	4	Rezende (2004) [47]
	Peromyscus gossypinus megacephalus	> WNV23397	29.397	5.6	35.3	29.7	O	0.191	0.0215	4	Layne and Dolan (1975) [43]
	Rattus fuscipes	> YP004123352	–30.17	4.8	32.9	28.1	O	0.492	0.0760	6	Dudley (1973) [48]
	Saccostomus campestris	> BAN15090	–25.33	4	32	28	O	0.419	0.0613	5.5	Dudley (1973) [48]
	Callospermophilus lateralis	> AEE11359	40.58	7	30	23	H	1.227	0.2570	5.5	Tattersall and Milsom (2003) [49]
	Tamiasciurus hudsonicus	> AEE11394	50.29	12	27	15	O	1.133	0.2310	5.5	Ferron (1981) [50]
	Thomomys talpoides	> AEE11412	37.44	6	32	26	H	0.632	0.1060	3.5	Nevo et al. (1974) [51]
	Thomomys umbrinus	> AGN56415	36.15	8	35	27	H	0.535	0.0850	3.5	Mathis et al. (2013) [52]

Table 1 Parameters related to physiological indicators of Rodentia and Chiroptera (*Continued*)

Order	Species	NCBI number	Latitude (°N)	TNZ (°C)	UTNZ (°C)	LTNZ (°C)	Dietary habit	BMR (W)	Body mass (kg)	Litter size (ind)	Reference
Chiroptera	*Anoura latidens*	> ABK57174	–18.293	1.5	36.2	34.7	H	0.135	0.0136	1	Calderón-Acevedo (2021) [53]
	Diaemus youngi	> WVN96457	–41.013	5	30	25	C	0.285	0.0366	1	Farlow and James (2005) [40]
	Erophylla bombifrons	> ANP94406	18.393	3	33	30	O	0.154	0.0161	1	Rodriguez-Duran (1995) [54]
	Glossophaga soricina	> WKV24137	–6.11	3.8	35.2	31.4	O	0.104	0.0096	1	Cabrera-Martínez et al. (2018) [55]
	Hipposideros diadema	> WVD59837	–5.211	5	34	29	C	0.288	0.0372	1	Bonaccorso and McNab (2003) [56]
	Hipposideros galeritus	> XLM23424	3.855	3	32	29	C	0.095	0.0085	1	Farlow and James (2005) [40]
	Hipposideros kingstonae	> WDV09553	–5.225	4	34	30	C	0.168	0.0182	1	Bonaccorso and McNab (2003) [56]
	Macroderma gigas	> YP010172278	–23.299	5	35	30	C	0.636	0.1070	1	Baudinette et al. (2000) [57]
	Macroglossus minimus	> WMW02355	–16.55	2.1	33	30.9	H	0.155	0.0163	1	Bartels et al. (1998) [58]
	Miniopterus schreibersii	> WNV23453	–12.275	5	37.5	32.5	C	0.115	0.0109	1	Baudinette et al. (2000) [57]
	Monophyllus redmani	> ANP94445	18.391	4	35	31	O	0.097	0.0087	1	Rodriguez-Duran (1995) [54]
	Myotis keaysi	> YP009442601	8.382	4.2	33.4	29.2	C	0.064	0.0050	1	Bejarano et al. (2007) [59]
	Noctilio albiventris	> AYJ72480	–20.055	6	38	32	C	0.226	0.0270	1	Farlow and James (2005) [40]
	Phyllostomus elongatus	> AEA89853	–41.015	11	36	25	O	0.279	0.0356	1	Farlow and James (2005) [40]
	Phyllostomus hastatus	> AEA37478	–41.014	10	35	25	O	0.531	0.0842	1	Farlow and James (2005) [40]
	Pteronotus personatus	> ABK57745	11.488	4.5	38.5	34	C	0.138	0.0140	1	Bonaccorso et al. (1992) [60]
	Pteropus poliocephalus	> QFU96067	–27.471	20	35	15	H	2.943	0.8250	1	Mcnab and Bonaccorso (1995) [61]
	Pteropus scapulatus	> AWA28299	–28.316	11	35	24	H	1.837	0.4400	1	Mcnab and Bonaccorso (1995) [61]
	Sturnira lilium	> AEA04813	–20.052	5.5	35.5	30	H	0.194	0.0219	1	Farlow and James (2005) [40]
	Tonatia bidens	> AMA19654	–41.016	7	35	28	O	0.229	0.0274	1	Farlow and James (2005) [40]

TNZ, thermal neutral zone; UTNZ, upper thermal neutral zone; LTNZ, lower thermal neutral zone; C, carnivorous; H, phytophagous; O, omnivorous; NCBI, national center for biotechnology information; BMR, basal metabolic rate.

branches. Finally, the evolutionary tree was refined using the iTOL online website (http://itol.embl.de) and Adobe Illustrator (2025) software.

Results

Distribution

Twenty-nine Rodentia and twenty Chiroptera were selected for this study, covering a latitudinal gradient from 42.453 °S to 61.410 °N, encompassing a diverse range of ecological and climatic conditions.

Effect of latitude on physiological indicators of the two major taxa

First, the effects of latitude on body mass, BMR, LTNZ, UTNZ and TNZ were explored separately for Rodentia and Chiroptera. Latitude showed significant correlations with body mass ($F = 12.270$, $P = 0.002$), BMR ($F = 14.241$, $P < 0.01$), LTNZ ($F = 24.395$, $P < 0.01$), UTNZ ($F = 7.212$, $P = 0.012$), and TNZ ($F = 31.713$, $P < 0.01$) in Rodentia, and with pterodactyls LTNZ ($F = 6.809$, $P = 0.018$) and TNZ ($F = 6.486$, $P = 0.020$) showed significant correlations, while the correlations with their body mass, BMR and UTNZ were not significant. In addition, only the effect of latitude on the average number of litters of Rodentia was investigated since Chiroptera usually give birth to only 1–2 litters, but the results showed that the correlation between latitude and the average number of litters of Rodentia was not significant ($F = 0.055$, $P = 0.816$).

Subsequently, LTNZ, and TNZ data for Rodentia and Chiroptera were combined to further observe the effect of latitude on the two major taxa (Figure 1). Latitude showed significant correlation with LTNZ ($F = 27.320$, $P < 0.001$) and TNZ ($F = 23.518$, $P < 0.01$) for both taxa.

The association between latitude and several key physiological indicators of these two major taxa was assessed by correlation heatmaps (Figure 2). The results showed significant correlations ($F = 8.501$, $P < 0.05$) between latitude and both LTNZ and TNZ, which were identical to the results of the linear regression analysis. Specifically, the selected high-latitude Rodentia and Chiroptera presented adaptive characteristics of reduced LTNZ and widened TNZ.

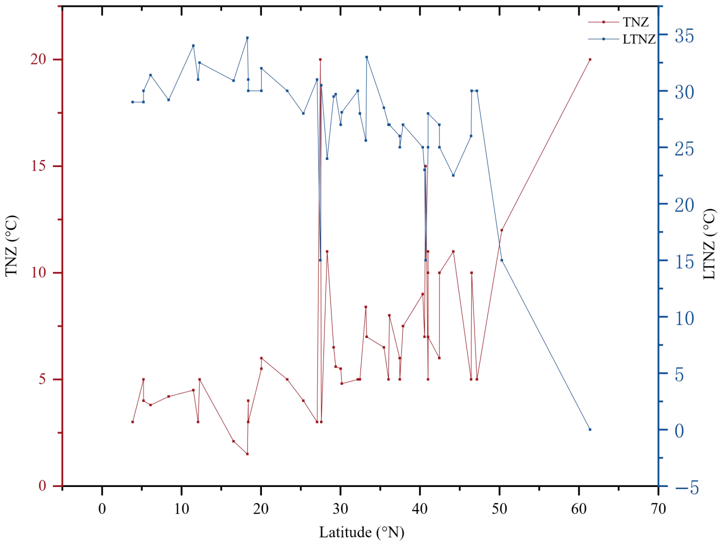
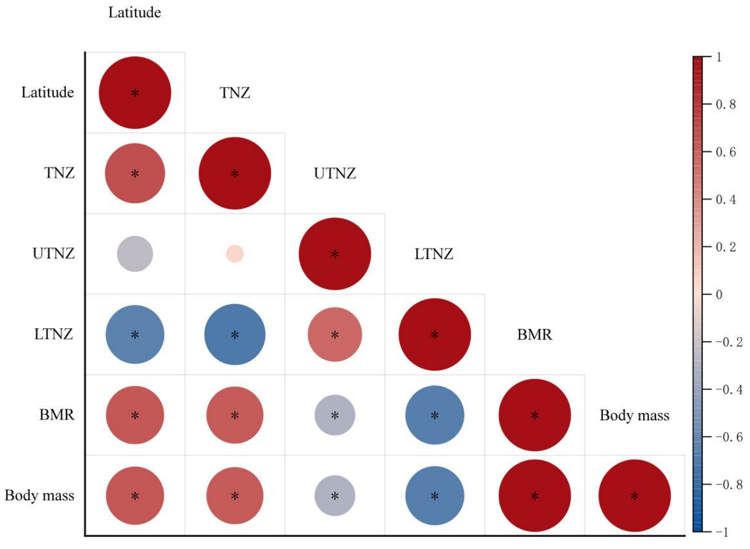


Figure 1 Trends in LTNZ vs. TNZ for Rodentia and Chiroptera at different latitudes. TNZ, thermal neutral zone; LTNZ, lower thermal neutral zone.



* p<=0.05; n=49

Figure 2 Heat map of correlations between multiple physiological indicators in Rodentia and Chiroptera. TNZ, thermal neutral zone; UTNZ, upper thermal neutral zone; LTNZ, lower thermal neutral zone; BMR, basal metabolic rate.

Influence of diet on physiological indices of the two major taxa

The dietary statistics of Rodentia and Chiroptera revealed that Rodentia were mainly omnivorous and phytophagous, and the average litter size of omnivorous animals was significantly higher than that of phytophagous animals ($F = 6.516$, $P = 0.017$), while Chiroptera were more diversified, including carnivorous, omnivorous and phytophagous (Figure 3). Subsequently, multifactorial histograms were utilized to represent the trends of BMR, LTNZ, UTNZ, TNZ, and litter size in Rodentia and Chiroptera with different diets (Figure 4).

The data on body mass, BMR, LTNZ, UTNZ and TNZ of Rodentia and Chiroptera were combined to explore the differences between physiological indices of the different predatory animals. The results showed that the differences in body mass, BMR, LTNZ, UTNZ and TNZ among the three food animals did not reach statistical significance.

Evolutionary tree of COX1 proteins of two major groups

Based on COX1 protein sequences, phylogenetic evolutionary trees of Rodentia and Chiroptera were constructed using the maximum likelihood method. The results showed that most Rodentia and Chiroptera formed two highly distinctly differentiated taxa (Figure 5).

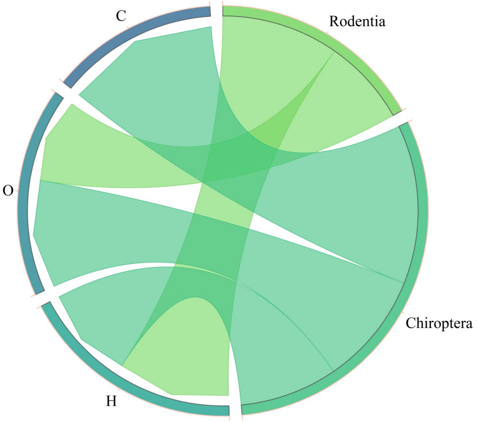


Figure 3 Rodentia and Chiroptera feeding chord diagrams. C, carnivorous; H, phytophagous; O, omnivorous.

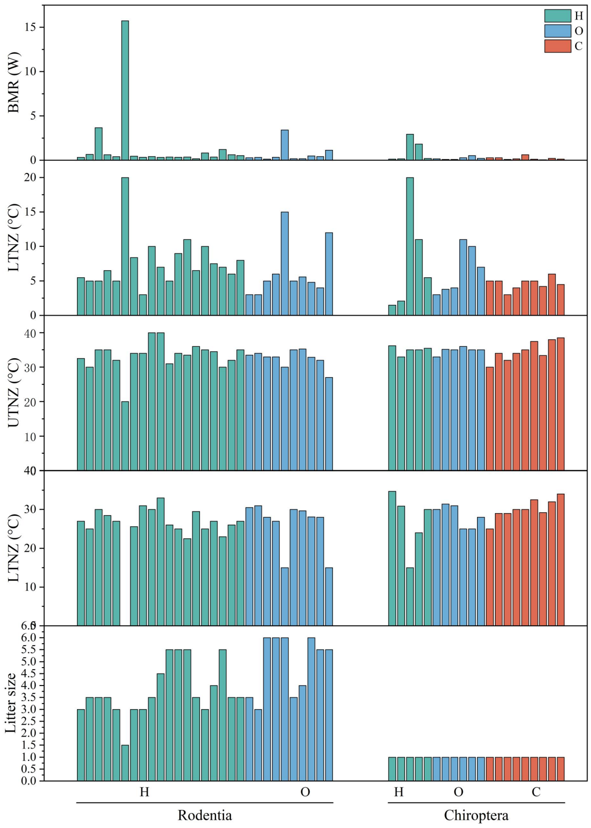


Figure 4 Multifactorial histogram combination of BMR, LTNZ, UTNZ, TNZ, and litter size in different species under different dietary conditions. C, carnivorous; H, phytophagous; O, omnivorous; UTNZ, upper thermal neutral zone; LTNZ, lower thermal neutral zone; BMR, basal metabolic rate.

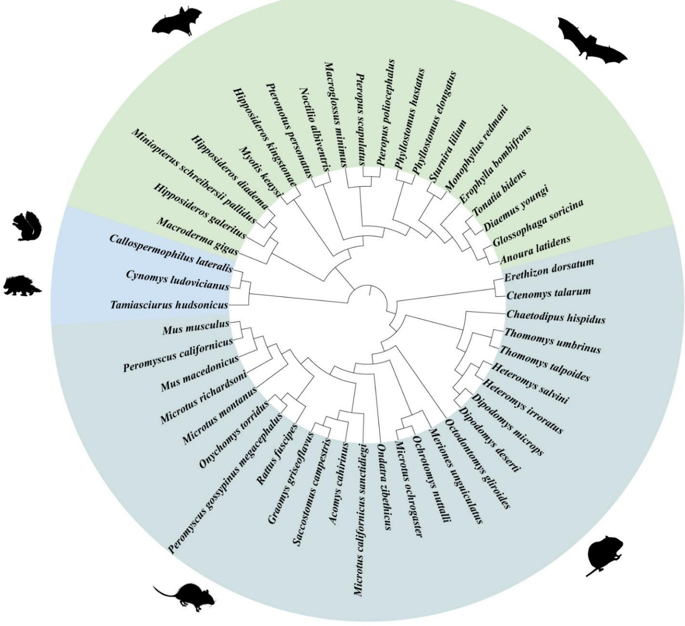


Figure 5 Phylogenetic tree of COX1 proteins in Rodentia and Chiroptera

Discussion

Body mass is influenced by many external factors such as temperature, light, quality and quantity of food, and one's own physiological state [62]. The present study showed that the body masss of the selected Rodentia increased with increasing latitude, a result that is the same as the conclusion proposed by Bergmann that the body size of thermostats increases with increasing latitude [63]. Similar results were also seen in birds, i.e., the increase in body mass in birds under low temperature conditions, which can be partially explained by changes in energy reserves or regulation of heat production made by the animals to adapt to environmental changes [64]. However, there was no significant correlation between body mass and latitude in the selected Chiroptera, which are more capable of flight, and it is hypothesized that they may have adapted to the environmental changes by migrating, decreasing protrusions, widening the TNZ, or other behaviors [65].

BMR is the minimum energy expenditure necessary for an animal to maintain cellular integrity and stability and is an important measure of vital activity [66]. Kleiber stated that there is a specific proportionality between BMR and body mass of an animal and that altering the ratio of heat production to heat dissipation is one of the mechanisms by which an animal maintains a high and constant body temperature [25]. Larger animals have a relatively smaller surface area and therefore can reduce heat dissipation by increasing their body size [67]. In this study, we found that Rodentia at high latitudes adopt adaptive metabolic strategies in response to harsher environmental conditions, i.e., reducing heat dissipation by increasing body mass and increasing BMR to maintain body temperature homeostasis. The adaptive strategy of elevating BMR by increasing body mass at low temperatures in high latitudes is also present in metabolic studies in laboratory mice [68, 69].

The TNZ is essentially the region in which an animal can maintain a minimum basal or resting metabolic rate level temperature under a range of ambient temperature changes, in which thermoregulation does not require thermogenesis and thermoregulation of heat dissipation [70, 71]. In the present study, both Rodentia and Chiroptera increased their tolerance to temperature fluctuations by decreasing the LTNZ and expanding the TNZ, a finding that is consistent with the results of Chen et al. on the thermogenic characteristics of small mammals and Yang et al. on highland indigenous animals, both of which suggest that with increasing latitude animals take to lowering the LTNZ and widening the TNZ to adapt to the low temperature environment at high latitudes [72, 73].

Animals have developed a variety of reproductive energy strategies over a long period of natural selection [74]. It was found that the effect of latitude on the average litter size of selected Rodentia was not significant, but omnivorous Rodentia had more average litters than phytophagous Rodentia. It is hypothesized that Rodentia with different diets may influence reproductive output through energy allocation strategies, with omnivorous Rodentia obtaining high-energy nutrients from a diverse diet and thus allocating more energy resources to reproduction, whereas phytophagous Rodentia may need to invest more energy into the digestive process, resulting in less energy available for reproduction. Many studies have shown that reproduction and litter size have complex patterns that are influenced by many factors such as latitude, nutrition, climate, and population density [75, 76]. Animals are able to adjust the timing of their litters according to the nutritional needs of their litters, synchronizing the timing of their litters with the optimal time in the environmental climate, and thus improving pup survival [77]. Therefore, throughout the life of a small mammal, no single reproductive strategy is always optimal, and more in-depth studies on the relationship between their reproductive characteristics and environmental factors are needed subsequently.

Khan et al. performed species identification and phylogenetic analysis of common house crow (*Corvus splendens*) by COX1 gene and Elzain et al. used COX1 gene to study Schistosoma aegypti haplotypes in western Sudan [78, 79]. Therefore, in the present study, evolutionary tree construction of Rodentia and Chiroptera by COX1 protein sequences revealed significant genetic differentiation between these two taxa during evolution. The topology of the evolutionary tree supports the status of Rodentia and Chiroptera as independent order-level taxonomic units in traditional taxonomy, and also provides molecular evidence for understanding the phylogenetic relationships of these two taxa. This result further validates the reliability of the COX1 gene in species identification and phylogenetic reconstruction [80, 81].

Conclusion

This study examines the adaptive changes in key physiological indicators such as body mass, BMR, LTNZ, UTNZ, and TNZ between rodents and pteropods in the context of latitudinal shifts, which is important for revealing the evolutionary history of these two major groups of species under the latitudinal gradient. The shift from low to high latitudes has been a major factor in the evolution of these two groups of species, and it is important to understand the relationship between these two groups. To maintain a constant body temperature, most of the Rodentia in this study had increased body mass to reduce heat loss by decreasing the body surface area to volume ratio and increased BMR to increase the efficiency of heat production to maintain body temperature homeostasis. In addition, both selected high-latitude Rodentia and Chiroptera adapted to variable environments by decreasing LTNZ and increasing TNZ. Finally, cross-taxon phylogenetic analyses based on the COX1 protein confirmed the value of this gene for species identification. These results provide a reference point for the study of adaptive changes in mammals in response to latitudinal shifts.

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