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Seasonal Influence on the Diurnal Behaviours of the Indian Flying Fox (*Pteropus medius*) in Lucknow, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study investigates the impact of seasonal changes on the diurnal behaviours of the Indian flying fox, *Pteropus medius*, at seven different roosting colonies in Lucknow, Uttar Pradesh, India. Behaviours of *P. medius* were categorized into roosting behaviour (hang relaxed, hang alert, wing droop, swivel, sleep), stationary actions (stretch, sniff, wing fan, yawn, wing flick), auto-grooming behaviour (general groom, wing groom), and locomotory behaviour (quadrupedal movement, bipedal movement). Seasonal influences on these behaviours were analyzed with respect to physical factors such as temperature (ºC) and humidity (%). Roosting behaviour was the most

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frequently observed category, followed by stationary actions, grooming, and locomotion. During the summer, bats increase wing fanning and seek out dense canopies to stay cool. In contrast, during the winter, they prefer to roost at the tops of trees or in trees with less canopy cover, where they spread their wings to bask in the sun and reduce wing fanning. In the summer, bats are drawn to dense canopy trees like *Mangifera indica* (with a canopy width of 12.64±2.63), while in the winter, they opt for trees with sparser canopies such as *Eucalyptus* species (canopy width of 7.60±4.06) and *Bambusa* species (canopy width of 2.00±0.00). These seasonal behaviours emphasize the significant role of sunlight and temperature. Seasonal averages temperature and humidity were recorded as 32.07±2.49°C and 63.10±10.09% in summer, 29.55±1.86°C and 86.75±3.68% in rainy season, 24.92±2.29°C and 82.00±4.68% in monsoon, and 17.69±2.70°C and 78.65±7.41% in winter. A correlation matrix plot demonstrated significant behavioural associations, notably a high positive correlation between wing fanning and grooming. There were no significant differences in diurnal behaviours in male and female. However the several behaviour including hang alert, hang relaxed, wing fan, general groom, quadrupedal movement, swivel, and stretch differ among sexes. Regression analysis showed that higher summer temperatures increased wing fanning in both male ($p=0.0348$) and female ($p=0.0362$) bats for thermoregulation, and higher roost temperatures were marginally linked to reduced sleep time, suggesting higher energy expenditure. This study highlights the adaptive behaviours of *P. medius* in response to seasonal climatic variations, providing insights essential for the conservation of the species.

Keywords: Bats; behaviour; diurnal behaviour; pteropus medius; roost temperature.

1. INTRODUCTION

Bats form the second-largest group of mammals with about 1,469 species worldwide and stand out as the only flying mammal [1]. Within this diverse group, the Old-World fruit bats are especially notable for their adaptation to tropical climates. Among the fruit bats (Family: Pteropodidae), the Indian flying fox, *Pteropus medius* (Temminck, 1825) stands out as one of the largest and most prominent bat species in the world [2-3]. It is widely distributed throughout southern and southeastern Asia [4-7]. They play essential ecological roles, such as dispersal of plant seeds and pollination of various flowering plants [8-9]. Indian flying foxes are known to live more than half of their lives in large diurnal aggregations, or "communal roosts," hidden among the leaves and twigs of trees [10]. Environmental factors greatly influence the roosting behaviour of many communal roosting species [11]. At higher temperatures, the bats display thermoregulatory behaviours such as licking their fur, spreading their wings and panting to dissipate heat [12]. The wing fanning is considered as a thermoregulatory behaviour particularly observed in *Pteropus* species [13]. Unlike many mammals, members of the family Pteropodidae generally lack sweat glands [14-15] and some species compensate by enhancing evaporative cooling through salivating and licking their wing membranes in high temperatures [13]. Seasonal changes impose varying physiological demands on these animals [16]. Despite their ecological importance, few studies were performed on the diurnal behaviour of Indian flying foxes [17-20]. The lack of research poses challenges for the conservation of vital mammalian species including flying foxes [21]. Understanding how environmental factors influence specific behaviours is crucial for the conservation and management of wild animals. Therefore, this study aims to explore the seasonal influences on the diurnal behaviours of the Indian flying fox, *Pteropus medius*.

2. MATERIALS AND METHODS

2.1 Study Area

The study was carried out from July 2021 to July 2022 at seven different roosting sites in the urban, semi-urban and rural localities within the Lucknow district. These roosting sites serve as a major communal roosting site for *P. medius.* The roosting sites are marked by a mix of greenery, parks, agricultural fields and water bodies which are occupied by common trees such as Neem (*Azadirachta indica*), Mango (*Mangifera indica*), Peepal (*Ficus religiosa*) and Eucalyptus (*Eucalyptus sp*.) which serves for roosting and feeding resources for bats. Lucknow covers an area of 3,244 sq. km and is situated 123 mts above sea level. It experiences an extreme continental climate, with continental air dominating for most of the year due to its distance from the sea. The summer is extremely hot with temperature often exceeding 40 °C. The monsoon season brings significant rainfall with an average annual precipitation of about 1,000 mm. The winter is mild and pleasant with temperatures ranging from 7°C to 25°C.

2.2 Data Collection

A field survey was conducted at regular intervals of two days per week at the roost site of *Pteropus medius*. The roost location was obtained using a handheld GPS device (Garmin Montana 680). Tree characteristics of roost trees were assessed such as tree sp., canopy width and canopy height. To calculate Tree Canopy Width (CW), the tree was observed from all sides to identify the side where the canopy is widest. Place two range poles at the farthest edges of the canopy. Measure the distance between these poles using a measuring tape and record it as the canopy width [22]. To calculate canopy height, position the stick so it only covers the tree canopy. Measure the length of the stick above your hand to determine side 'b'. Next, measure the distance from your eye to the top of your hand (a). Then, measure the distance from your eye, past your hand, to the base of the tree (A). Calculate the tree height (TrH) using the formula: TrH = A / (a * b) [23]. Colony size was assessed by counting the number of bats on individual trees and summing the counts of individual trees [24-25]. Temperature (°C) and relative humidity (%) data were collected at the roost sites during the morning (7:00 AM-9:00 AM) and afternoon (12:00 PM-2:00 PM) to assess the impact of climate variables on the behaviour of *Pteropus medius*. Diurnal behaviours of *P. medius* such as sleeping, grooming, wing fanning, wing stretching, yawning and fighting served as binoculars for distant viewing of them (ACULON A211, NIKON) and snapped a photo using a digital camera (Nikon D5200). A group of bats occupying a branch was randomly selected for observation of group size. Visual observations were conducted to assess various behaviours of bats [21, 26]

2.3 Data Analysis

The ANOVA test results indicated that the observed incidences of each behavioural presentation were dispersed in an appropriate manner. Therefore, non-parametric statistical tests were applied to additional behavioural analysis. First, we performed one-way ANOVA to find out if any behavioural differences exist between the gender (male and female) of *P. medius* with respect to season considering findings that fruit bat behaviour varies with the seasons [27]. Second, we performed a two-way ANOVA to find out if any significant differences exist between male and female's diurnal behaviour corresponding to seasons. In order to assess the relationship between each instance of the diurnal roosting behaviour displayed by the Indian flying fox, we finally calculated the correlation matrix plot. We also used regression analysis to find out the significance of temperature on diurnal behaviours. Utilizing the software programs PAST and SPSS, statistical tests were calculated. A mean ± standard deviation (SD) was used to present the data.

3. RESULTS

The present study was conducted at seven roosting sites in Lucknow namely Aishbagh, Anora, Khurdahi, Meenapur, Mohanlalganj, Natkur and Soharamau. The average population at these roosting sites and the specifics of the roost trees are outlined in Table 1, while details on canopy height and width are provided in Table 2. During the summer, bats show a preference for trees with dense canopies, such as *Mangifera indica* (canopy width = 12.64±2.63), whereas in winter, they favor trees with less dense canopies, like *Eucalyptus* species (canopy width = 7.60±4.06) and *Bambusa* species (canopy width = 2.00±0.00). Information regarding the distance from human habitation and water resources is detailed in Table 3. An ethogram was prepared listing all diurnal roosting behaviours of *P. medius*. The behavioural displays were categorized into four broad classes: roosting behaviour, stationary actions, locomotion and auto-grooming behaviours (Table 4). Roosting behaviour was the most frequently recorded behaviour (hang relaxed, hang alert, wing droop, swivel and sleep), followed by stationary actions (stretch, sniff, wing fan, yawn and wing flick), auto-grooming behaviour (general groom and wing groom), and locomotion behaviour (quadrupedal movement and bipedal movement) (Table 4).

Temperature and humidity fluctuated with the seasons at the roosting sites of *P. medius*. The average temperature was recorded 32.07±2.49 °C in summer, 29.55±1.86 °C in rainy season, 24.92±2.29 °C in monsoon and 17.69±2.70 °C in winter (Fig. 2). The average humidity levels were 63.10±10.09 % in summer, 86.75±3.68 % in rainy season, 82.00±4.68 % in monsoon, and 78.65±7.41 % in winter (Fig. 1).

Table 1. Details of roost sites include GPS location, roost tree species and number of roost trees, roosting area and colony size of *Pteropus medius*

S. No.	Place	GPS N	GPS E	Roost tree (Number)	Colony size (Average±SD)
1	Aishbagh	26'50.544	80'54.448	*Eucalyptus sp.* (4), *Ailanthus excelsa* (2), *Tectona grandis* (13), *Azadirachta indica* (2), *Phernandoa adenophyla* (19), *Terminalia arjuna* (1)	819.6 ± 464.9
2	Anora	26'46.629	080'50.824	*Eucalyptus sp.* (3), *Ficus racemose* (11), *Tectona grandis* (2), *Mangifera indica* (2), *Azadirachta indica* (5), *Bamboo sp.* (1), *Artocarpus lacucha* (1), *Ficus religiosa* (1), *Limonia acidissima* (1)	1898.1 ± 751.1
3	Khurdahi	26'46.990	081'02.913	*Mangifera indica* (13)	889.1 ± 261.2
4	Meenapur	26'36.220	080'55.062	*Eucalyptus sp.* (10),*Syzygium cumini* (1),*Madhuca longifolia* (1)	373.3 ± 214.1
5	Mohanlalganj	26°41'10.59	80°59'1.63	*Eucalyptus sp.* (46)	1836.2 ± 662.4
6	Natkur	26'43.751	080'52.038	*Mangifera indica* (5), *Syzygium cumini* (2)	252.7 ± 117.2
7	Soharamau	26'46.807	081'08.196	*Mangifera indica* (17),*Syzygium cumini* (1),*Ficus racemosa* (1),*Eucalyptus sp*. (3)	1228.8 ± 183.7

Table 2. Average and SD of roost tree canopy width and canopy height

S.No	Roost tree	Roost tree canopy width (meter)	Roost tree canopy height (meter)
1	*Terminalia arjuna* (1)	14.02±0.00	16.45±0.00
2	*Bambusa sp*.(1)	2.00±0.00	9.41±0.00
3	*Ficus racemosa* (12)	10.21±1.84	8.26±2.20
4	*Eucalyptus sp*. (66)	7.60±4.06	10.94±5.28
5	*Syzygium cumini* (4)	10.59±3.18	13.75±2.89
6	*Fernandoa adenophylla* (19)	9.75±0.86	14.47±1.07
7	*Madhuca longifolia* (1)	20.11±0.00	13.10±0.00
8	*Mangifera indica* (37)	12.64±2.63	13.45±2.48
9	*Artocarpus lacucha* (1)	7.31±0.00	7.92±0.00
10	*Azadirachta indica* (7)	8.87±2.05	5.79±1.73
11	*Ficus religiosa* (1)	9.14±0.00	6.40±0.00
12	*Tectona grandis* (15)	8.83±1.66	5.48±2.03
13	*Ailanthus excelsa* (1)	18.28±0.00	9.14±0.00
14	*Limonia acidissima* (1)	16.15±0.00	9.12±0.00

Table 3. Distance from roost area to human habitation and water body

S. No.	Place	Roost area	Distance from roost area to human habitation (meter)	Distance from roost area to water body (meter)
1	Aishbagh	Urban	45.72	167.0304
2	Anora	Rural	6.7056	97.536
3	Khurdahi	Rural	79.248	3.6576
4	Meenapur	Rural	16.764	68.58
5	Mohanlalganj	Sub urban	93.2688	196.596
6	Natkur	Rural	95.3262	699.8208
7	Soharamau	Rural	76.2	1.524

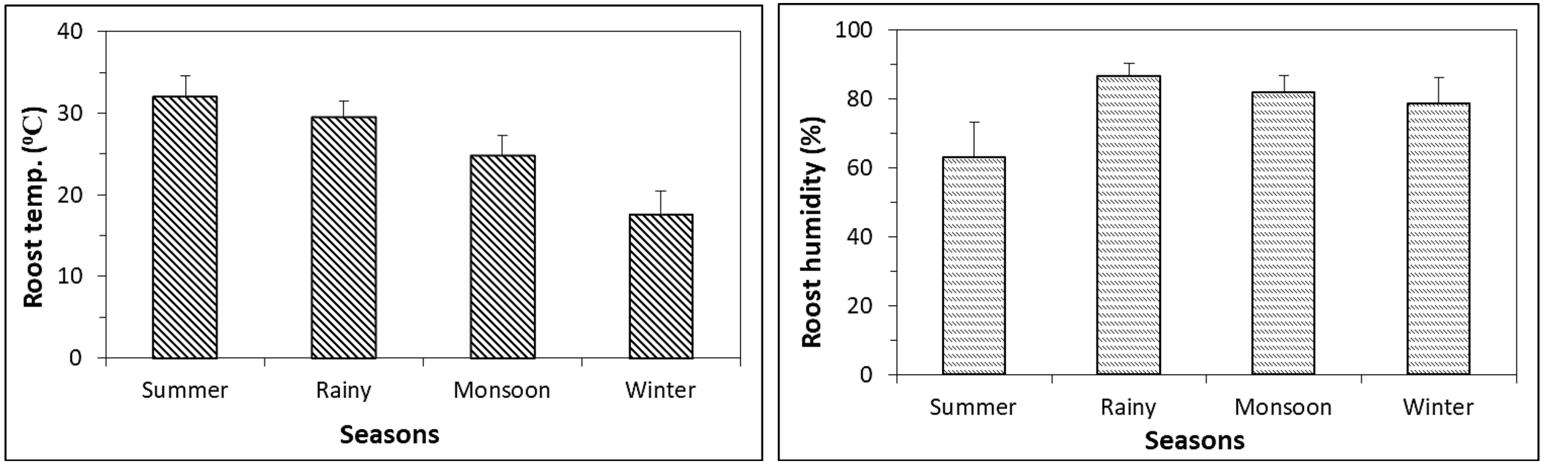

Fig. 1. Seasonal fluctuations of temperature (°C) and humidity (%) were recorded at *Pteropus medius* roosting sites throughout the study period

Table 4. Frequencies of various diurnal behaviours of *Pteropus medius* observed during summer, rainy, monsoon and winter seasons. The values are given as Mean ± SD

Diurnal behaviours		Summer		Rainy		Monsoon		Winter	
		Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
Roosting behaviour	Hang relaxed	62.4 ± 58.7	22.3 ± 18.3	130.5 ± 75.6	70.3 ± 36.1	47.0 ± 60.8	59.3 ± 65.0	34.5 ± 10.4	55.5 ± 25.5
	Hang alert	134.2 ± 118.3	61.0 ± 42.7	322.0 ± 115.9	106.0 ± 40.1	287.0 ± 347.8	174.3 ± 184.9	95.5 ± 49.3	71.2 ± 38.0
	Wing droop	53.0 ± 35.8	6.3 ± 4.5	82.5 ± 6.3	39.0 ± 19.6	81.0 ± 49.4	33.3 ± 30.0	46.0 ± 31.8	31.0 ± 15.6
	Swivel	2.0 ± 1.0	1.0 ± 1.4	16.0 ± 7.0	4.0 ± 3.0	7.0 ± 8.4	6.6 ± 8.0	5.2 ± 5.5	7.7 ± 12.3
	sleep	3.0 ± 5.6	5.0 ± 1.7	1.0 ± 1.4	15.5 ± 13.4	8.0 ± 2.8	28.0 ± 22.6	31.2 ± 27.9	44.5 ± 39.1
Stationary action	Stretch	21.8 ± 18.4	10.6 ± 4.5	124.0 ± 1.4	38.3 ± 10.5	46.5 ± 51.6	29.0 ± 18.1	16.7 ± 18.1	15.7 ± 12.9
	Sniff	26.2 ± 21.9	4.0 ± 1.7	60.5 ± 31.1	6.0 ± 2.8	46.5 ± 57.2	10.0 ± 7.0	14.2 ± 6.8	4.0 ± 3.9
	Wing fan	44.6 ± 22.6	43.5 ± 19.2	34.8 ± 2.4	24.0 ± 17.3	33.5 ± 0.0	28.2 ± 18.9	8.7 ± 6.2	2.8 ± 1.7
	Yawn	23.5 ± 28.9	2.6 ± 0.5	3.0 ± 1.4	3.0 ± 1.7	1.0 ± 0.0	3.0 ± 2.8	1.0 ± 1.1	2.7 ± 2.8
	Wing flick	6.8 ± 2.7	2.0 ± 2.0	4.5 ± 0.7	1.0 ± 0.0	2.0 ± 0.0	9.6 ± 14.1	1.2 ± 1.8	3.0 ± 2.8
Locomotion	Bipedal movement	8.0 ± 7.5	4.6 ± 4.7	14.0 ± 4.2	3.6 ± 2.3	20.0 ± 0.0	3.6 ± 3.7	0.2 ± 0.5	2.0 ± 1.4
	Quadrupedal movement	16.8 ± 13.8	5.2 ± 3.4	33.5 ± 6.3	6.6 ± 4.7	32.5 ± 31.8	17.6 ± 19.8	10.0 ± 9.3	3.7 ± 1.7
Auto groom	General groom	26.6 ± 19.9	18.5 ± 17.6	82.0 ± 16.9	47.6 ± 34.7	43.5 ± 36.0	85.3 ± 62.8	38.7 ± 21.8	45.7 ± 18.0
	Wing groom	23.0 ± 16.0	5.6 ± 5.1	0.0 ± 0.0	12.6 ± 3.5	22.0 ± 0.0	15.0 ± 0.0	8.0 ± 7.3	13.0 ± 9.5

3.1 Statistical Analysis

The behavioural relationships of *Pteropus medius* were visualized using a correlation matrix plot, which provides a numerical summary of different behaviours and their associations throughout the seasons (Fig. 2). Fourteen frequently observed behaviours at roosting sites were analyzed. The correlation matrix plot values range from -1 to 1, representing the strength and direction of the linear relationship between pairs of behaviours.

Key observations from the correlation plot include:

- Wing fanning and wing grooming have a high positive correlation, indicated by a dark blue large circle.
- Stretching and swiveling show a moderately positive correlation, represented by a moderate blue circle (correlation: 0.554).
- Yawning and stretching exhibit a weak negative correlation, indicated by a moderate red circle (correlation: -0.273).
- Quadrupedal movement and wing fanning also have a moderate negative correlation, shown by a moderate red circle (correlation: -0.341).
- General grooming and wing fanning have a moderate positive correlation (correlation: 0.318).
- Wing fanning and wing grooming show a very high positive correlation (correlation: 0.649).

The correlation plot makes it easy to quickly understand which behaviours tend to occur together and which do not, providing insights into the behavioural patterns of *P. medius*.

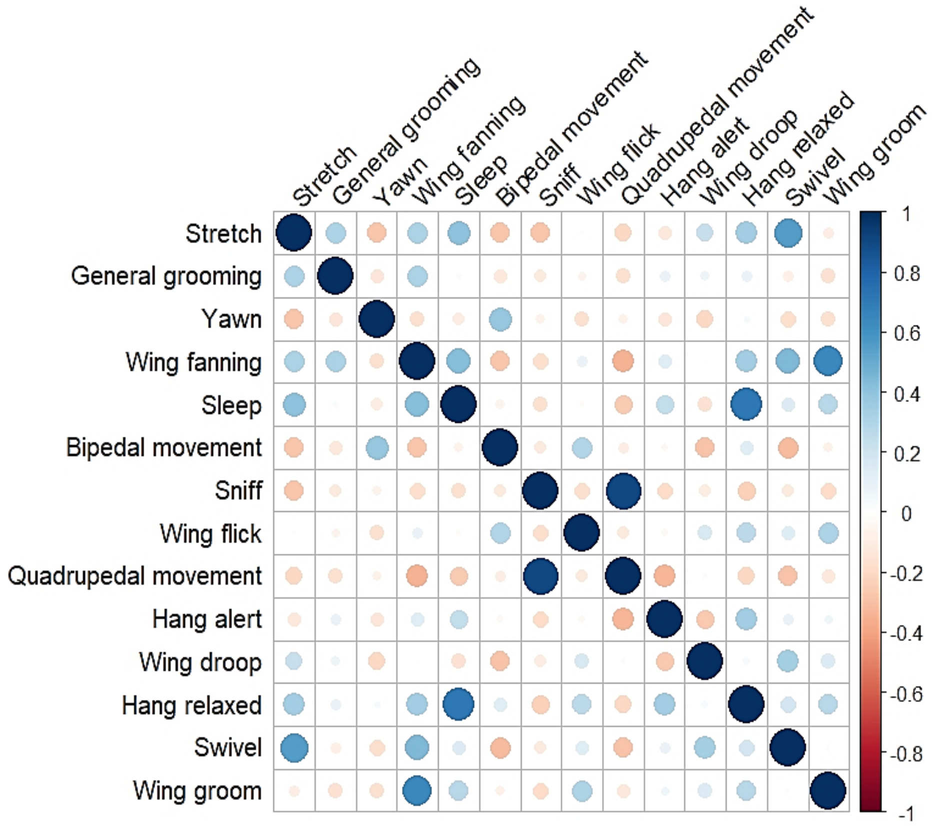

Fig. 2. The correlation matrix provides a numerical summary of relationships between different behaviours of *Pteropus medius* with values ranging from -1 to 1, indicating the strength and direction of the linear relationships. In the plot, larger and darker circles indicate stronger correlations, whether positive (shown in blue) or negative (shown in red). No or weak correlations are represented by lighter colours or smaller circles

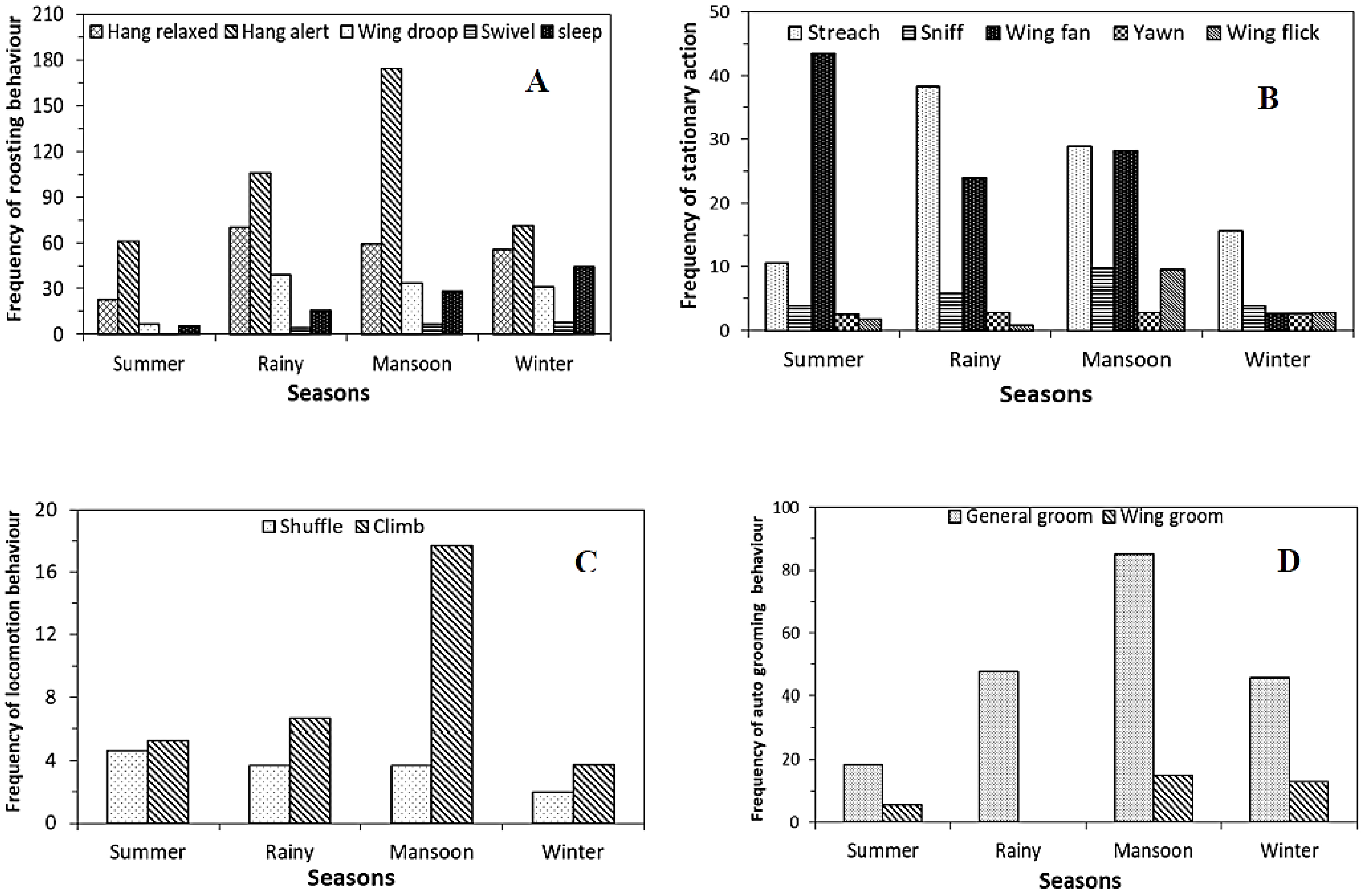

Fig. 3. Behavioural changes with response to weather conditions in all the seasons. A. hang relaxed, hang alert, wing droop, swivel, sleep, B. Stretch, sniff, wing fanning, yawn, wing flick, C. bipedal movement, quadrupedal movement, D. General groom, wing groom

3.2 Effect of Season on Behaviours of *Pteropus medius*

Bats occupied in the open canopy and directly influenced by weather conditions including changes in temperature, rainfall, relative humidity and wind velocity which can influence the roosting behaviours of *P. medius* (Fig. 3). Behavioural changes in *P. medius* vary with the seasons. During the summer, bats engage in rapid wing fanning and choose to roost under dense canopies of trees to stay cool. In contrast, during the winter, they roost at the top of trees, spreading their wings to sunbathe in moderate sunlight with the frequency of decreased wing fanning. These behaviours highlight the significant influence of sunlight and temperature on their seasonal activities. Additionally, in the severe winter, bats exhibit other thermoregulatory behaviours such as covering their bodies with their patagium and roosting in a big clumped form by cuddling together, including males, females, pups, and sub-adults to maintain an optimal body temperature. In this study, behavioural fluctuations due to seasonal changes were tested using a two-way ANOVA on combined data. The results showed no statistically significant difference in diurnal behaviour between male and female *P. medius* across seasons (P=1). However, one-way ANOVA results indicated significant differences in several behaviours, such as hang alert, hang relaxed, wing fan, general groom, quadrupedal movement, swivel, and stretch in both male and female *P. medius*, suggesting that these behaviours were significantly affected by the seasons.

Based on ANOVA, the behaviours such as hang alert ($p<0.001$) and general grooming ($p<0.001$), hang relaxed ($p<0.001$), wing fanning ($p=0.0123$), quadrupedal movement ($p<0.001$), stretch ($p=0.0164$) and swivel ($p<0.01$) were significant.

Seven behaviours were non-significant with yawn ($p=0.0966$) and bipedal movement ($p=0.0899$) being borderline, and sleep ($p=0.512$), sniffing ($p=0.217$), wing droop ($p=0.148$), wing groom ($p=0.434$), and wing flick ($p=0.844$) being non-significant. These results indicate that certain behaviours change significantly with the seasons, but gender and its interaction with the season do not have a significant impact.

Temperature is a key factor influencing these behavioural changes. Regression analysis showed that wing fanning and sleep are the main behaviours affected by temperature. In the summer, higher temperatures lead to increased wing fanning in both male ($p=0.0348$) and female ($p=0.0362$) bats, indicating that bats engage in wing fanning to regulate body temperature and cool down. Additionally, higher roost temperatures are marginally associated with reduced sleep time in both male ($p=0.0570$) and female ($p=0.0622$) bats, suggesting a trend where increased roost temperature may lead to less sleep and increased alertness, resulting in higher energy expenditure during the summer compared to other seasons.

4. DISCUSSION

The behavioural adaptations of the Indian flying fox, *Pteropus medius*, to seasonal and climatic variations highlight the species' intricate strategies for coping with environmental challenges. These behavioural changes are crucial for the bats' thermoregulation, energy conservation, and overall survival. Our observations reveal that during the summer months, *P. medius* significantly increases wing fanning and wing spreading behaviours. These behaviours are essential for thermoregulation, as they help dissipate excess body heat. The intensified wing fanning in the summer is consistent with findings in other fruit bats, such as the grey-headed flying fox (*Pteropus poliocephalus*), which also exhibit increased wing flapping and spreading during high temperatures [26]. This parallely suggests that wing fanning and spreading are effective behavioural adaptations for cooling in fruit bats, compensating for their lack of sweat glands [28,12]. Conversely, during winter, *P. medius* alters its roosting behaviour to seek canopy cover at the top of roost trees. This behaviour likely maximizes sun exposure, aiding in heat conservation during colder periods. This shift aligns with observations in other bat species, where increased sun exposure is used for thermoregulation in cooler climates [29,17]. The reduced frequency of wing spreading in winter further supports the idea that lower temperatures diminish the need for cooling behaviours, emphasizing the bats' focus on conserving body heat.

The seasonal variation in diurnal behaviours of *P. medius* also includes changes in activity patterns based on ambient temperature. In warmer conditions, the bats increase their wing flapping and fanning behaviours to cool down. In contrast, cooler conditions see a decrease in these behaviours, with the bats engaging more in resting and grooming activities, often clustering together. This pattern of increased activity during warmer periods and energy conservation during cooler periods is consistent with findings from other bat studies [30-31].

While our study provides a detailed account of the behavioural adaptations of *P. medius* to seasonal and climatic variations, it also underscores the need for further research. Specifically, future studies should investigate the long-term health consequences of these behavioural adaptations and how reproductive status affects responses to temperature changes [32-33]. Understanding these aspects will offer a more comprehensive insight into the ecological and evolutionary dynamics of fruit bats in response to environmental challenges.

5. CONCLUSION

Our study on the Indian flying fox, *P. medius*, highlights how seasonal and climatic conditions drive a variety of behavioural adaptations crucial for their survival. During the summer, these bats employ wing fanning and spreading to manage high temperatures, consistent with known thermoregulatory strategies of fruit bats. In winter, they adjust by roosting under dense canopy cover and reducing wing spreading by covering the body by wing or by clumping together to minimize heat loss and maintain optimum body temperature. We also observed that *P. medius* engages in unihemispheric slow-wave sleep, a behaviour that aids in both energy conservation and vigilance. These findings reflect the species' ability to adjust its behaviours in response to environmental changes and align with broader patterns observed in other fruit bat species. Future research should explore the long-term health impacts of these behaviours and investigate how reproductive status affects their responses to climatic variations. Overall, *P. medius* demonstrates a range of adaptive behaviours that support its resilience to seasonal and climatic fluctuations.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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