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Relationship between wingbeat frequency and body mass in two dipteran synanthropic flies, *Musca domestica* and *Sarcophaga ruficornis*

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Abstract
The synanthropic flies are frequently encountered in and near residential areas and they pose a threat to public health. *Musca domestica* and *Sarcophaga ruficornis* flies, locally collected and reared, were used to study the correlation between wing beat frequency and body mass. Male *Musca* flies had statistically significantly higher wingbeat frequency, Mean±SE (268.46±.99 Hz) than females (263.45±.73 Hz), p<.001. Similarly, Male *Sarcophaga* flies had statistically significantly higher wingbeat frequency (243.37±.55 Hz) than females (238.08±.35 Hz), p<.001. Mean wingbeat frequencies for females were lower than in males. Body weight ranged from 14 to 26mg, and 35 to 99 mg for *Musca* and *Sarcophaga*, respectively, with females generally heavier than the males. There was no statistically significant difference between the body weights of *Musca* males (22.37±.25 mg) and females (22.46±.24 mg), p=.781. However, female *Sarcophaga* flies (74.36±1.18 mg) were statistically significantly heavier than males (49.12±.71 mg), p<.001. Statistically significant negative correlations (p< .001) were observed between body weight and wingbeat frequency, and the association was strong (.7 < | r | < .9). Frequency was found to increase with decrease in body weight, which was consistent with other similar studies. The slope was steeper for males in both flies. Wingbeat frequency in dipterans reflects flight activity and efficiency by playing an important role of impacting longevity and fitness such as the ability of forage and hunt, compete for a mate and evade predators.

Keywords: *Musca*, *Sarcophaga*, wingbeat frequency, body mass

Introduction
Synanthropic flies have adapted to live in close association with human habitations. Many are associated with unsanitary conditions, and capable of transmitting pathogens either mechanically or biologically through this close relationship. Being synanthropic, their niche overlaps and they compete for resources (Majumdar *et al*., 2011) [3]. Dipteran flies are some of the most impressive flyers of class Insecta,.and for them flight is as vital as for any winged insect as it impacts longevity and fitness, the ability of forage and hunt, compete for a mate and evade predators (Pollack, 2017, Mathew & Singh, 2017) [8, 4]. Two such most common synanthropic flies are the House flies (*Musca domestica* L.) and the Flesh flies (*Sarcophaga* sp.). *Musca* belong to the order Diptera, family Muscidae; and are cosmopolitan, ubiquitous, synanthropic insects that serve as mechanical or biological vectors for various microbes. They reproduce and develop in decomposing organic waste and therefore is constantly in contact with different species of microorganisms. These flies have long been considered vectors or transporters of pathogenic microorganisms (West, 1951), due to their coprophagous habits. Adults carry numerous kinds of pathogens, such as bacteria, viruses, fungi, and other parasites (Phoku *et al*., 2014) [7]. Flesh flies (*Sarcophaga* sp.) also belong to the order Diptera, family Sarcophagidae; and are cosmopolitan in distribution (Pape, 1996) [5]. They breed in carrion, dung, or decaying material, but a few species lay their eggs in the open wounds of mammals, hence their common name. They have holometamorphic life cycle and are larviparous.

Kinematic mechanism of aerodynamics and several other factors determine and govern the flight ability in flies (Dickinson & Tu, 1997) [2]. Although the aerodynamics of insect flight have been extensively researched, the sound produced during flight has received less attention. The buzzing or humming sound of flies is produced by the vibration of their wings (Brown, 1951) [1]. This sound helps many flies to communicate. Wingbeat Frequency (WBF) is an important component in the flight sound made by the wings when insects fly. Many studies have used different methods to determine WBFs using sound, radar, or optics to develop intelligent methods for automatic detection, recognition, and monitoring of flying insects (Parmezan *et al*., 2021) [6]. WBF is influenced by characteristics including as body weight, wing structure, and metabolic condition, in addition to the insect's size. WBF varies with insect size, body mass, age etc. This present study on WBFs of local *Musca domestica* and *Sarcophaga ruficornis* flies from the eastern part of Uttar Pradesh in India, is an effort to understand the aspects of insect flight.

Materials and method
The materials used were Insect trapping net, bioclimatic chamber, high-quality digital recording device with microphone and a computer with audio analysis software (Fig.1).

Insect Collection and rearing
Dipteridae members, *Musca domestica* and *Sarcophaga ruficornis*, were captured using an insect collecting sweep net. Collection was done during March-April at locations frequently sighted around like, fruit juice stands and chicken shops, in the eastern part of the state of Uttar Pradesh, India (26.85°N 80.91°E). The two species were identified and reared using standard laboratory rearing protocols a simple and time-saving rearing methods. Rearing was carried out in small containers, within controlled environment at 27±2°C in a 12:12 LD photoperiod at 60% relative humidity in the Centre for Environmental and Applied Entomology (CEAE) Lab, Department of Zoology, St. Andrew's College,

Gorakhpur. Newly emerged third generation flies were used for the experiments.

Free flight wingbeat frequency recording

The recording chamber was a glass cabin of 30 x 25 x 30cm. The recordings of 100 flies each of each sex and species were carried out at 27±2°C and 60% relative humidity in BOD chamber. The audio produced during flight was recorded at sampling rate of 44.1 kHz at 16-bit resolution using high-quality condenser microphone connected to a PC through a four-channel Behringer U-Phoria UMC404HD USB audio interface. The audio was recorded in wav. format without data compression. The microphone was placed within the bioclimatic chamber and the bees were allowed, one at a time, to fly freely within. Audio sample clips were taken of about 15 second duration. The flies were allowed spend time in the cabin along with the recorder (Fig. 1). The filtered audio were analysed using spectrogram analysis.

Acoustical Measurement and Analysis

For acoustical analysis RAVEN LITE version 1.0 for windows from the Cornell Lab of Ornithology-Bioacoustical Research Program and Reaper Version 6.25 (https://www.cockos.com/reaper/) were used. The audio files recorded in wav. format were equalised and filtered using digital graphic equalizer to filter out unwanted frequencies at low and high range of audio spectrum. The filtered audio was analysed for the average frequencies using spectrogram analysis and were reanalysed manually using online tone generator program (plasticity.szynalski.com/tone-generator.htm). This program was used to generate pure tone to match with the filtered audio of fly's wingbeat.

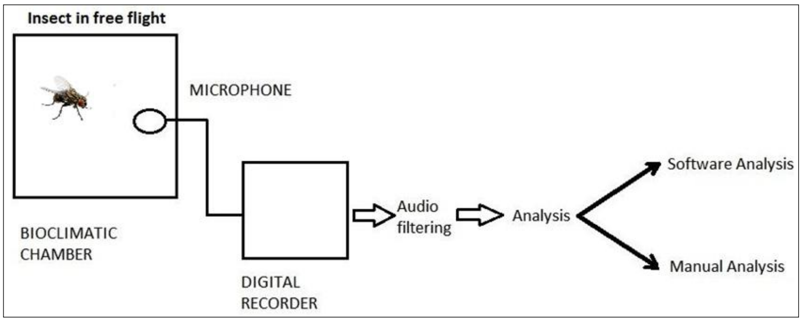

Fig 1: Schematic set-up for recording and analysis of flight sounds of fly (Mathew & Singh, 2017) [4]

Observation and Result

Wingbeat frequency during normal flight of *M. domestica* mostly ranged from 248 to 292 Hz, and that of *S. ruficornis* ranged from 232 to 254 Hz (Fig. 2,3). Male *Musca* flies had statistically significantly higher WBF Mean±SE (268.46±.99 Hz) than females (263.45±.73 Hz), t(198)=4.067, p<.001. Similarly, Male *Sarcophaga* flies had statistically significantly higher WBF (243.37±.55 Hz) than females (238.08±.35 Hz), t(198)=8.187, p<.001. Mean WBF for females were lower than in males. Body mass ranged from 14 to 26mg, and 35 to 99 mg for *Musca* and *Sarcophaga*, respectively, with females generally heavier than the males. There was no statistically significant difference between the body weights of *Musca* males (22.37±.25 mg) and females (22.46±.24 mg), t(198)=-.278, p=.781. However, female *Sarcophaga* flies (74.36±1.18 mg) were statistically significantly heavier than males (49.12±.71 mg), t(198)=-18.272, p<.001. For the same body weight, males generally showed higher WBF. This was much more evident in *Musca*, especially towards the lower weight region. In *Sarcophaga* this was same towards the lower body weight region however, females showed higher frequencies towards higher body weight region, as compared to that of males of similar weight.

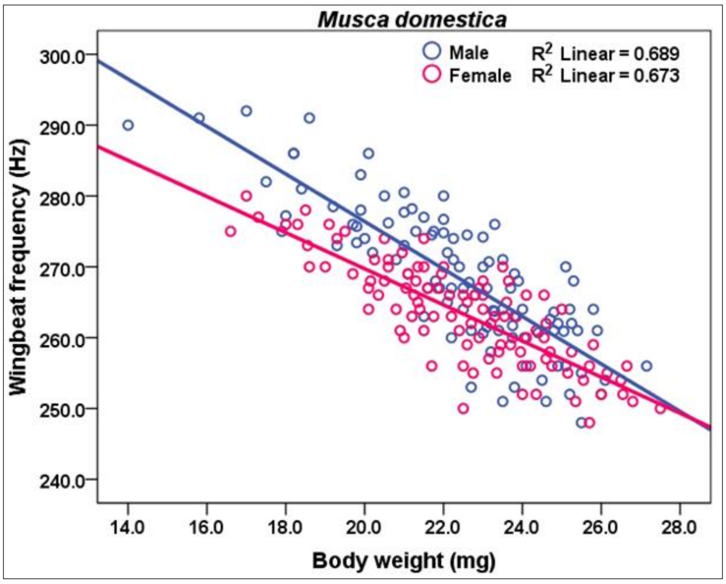

Fig 2: Correlation between wingbeat frequency and body weight of *Musca domestica*

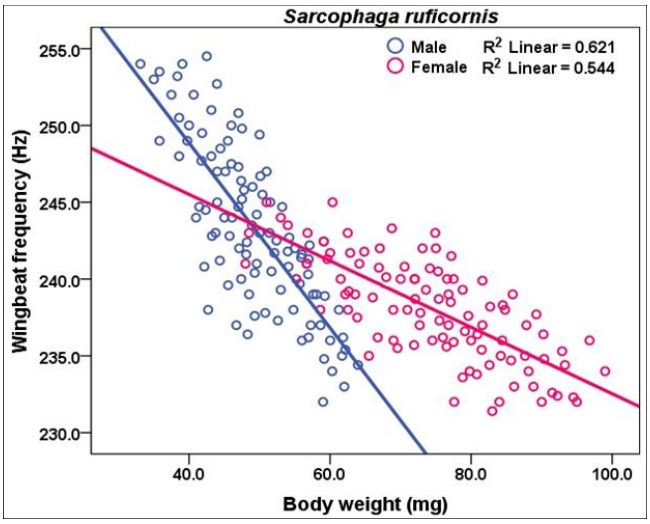

Fig 3: Correlation between wingbeat frequency and body weight of *Sarcophaga ruficornis*

Analysis of body mass and WBF showed statistically significant linear relationship ($p< .001$) with negative correlation for both species and sexes. The direction of relationship was negative, meaning that the WBF tends to drop with increase in body weight. The magnitude, or strength of association was strong ($.7 < | r | < .9$). Regression for the linear relationship between *Musca* male body weight and WBF was calculated to be $y = 343.41 – 3.35x$ and the strength of association was strong ($r=.830$). For female it was $y = 320.69 – 2.55x$ and the strength of association was strong ($r=.821$). Similarly, regression for the linear relationship between *Sarcophaga* male body weight and WBF was calculated to be $y = 272.95 – .60x$ and the strength of association was strong ($r=.788$). For female it was $y = 254.16 – .22x$ and the strength of association was strong ($r=.738$).

Discussion

Wingbeat frequency in insects is an important variable in aerodynamic and energetic analyses of insect flight. In both the flies the WBF was found to increase with decrease in body weight, which was consistent with other similar studies (Tercel *et al*., 2018) [10]. However, the slope was steeper for males in both flies. *Musca* and *Sarcophaga*, respectively, with females generally heavier than the males. It means, for the same body weight, males generally showed higher WBF, especially towards the lower weight region. This was observed in the case of *Musca*, and the same was seen in *Sarcophaga*, however, in the latter females showed higher frequencies towards heavier body weight region, as compared to that of males of similar weight. WBF is directly related to energy consumption and is a strong indicator of its rate of metabolism and physical structure. WBF is inversely related to the length of its wing and to the mass of its body (Santoyo *et al*., 2016) [9]. Even though the WBFs were close in their values within each group, variations did exist. These differences can be attributed to the varying size of the flies and of the wings as well.

It is generally seen that larger the fly and its wings, the lower the frequency as it will take more time for longer wings to complete one full up and down motion, therefore beating fewer times per second (Mathew & Singh, 2017) [4]. Wing structure, width, length and muscular components may also be different in each type of fly across the larger group. WBF directly depends upon several factors like insect's body weight, wing structure, age, metabolic status, locomotory requirements, ambient climatic factors, etc. (Unwin & Corbet, 1984) [11]. WBF in dipterans reflects flight activity and efficiency by playing an important role of impacting longevity and fitness such as the ability of forage and hunt, compete for a mate and evade predators.

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