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Butterfly foraging strategies and their interactions with some selected nectar plants

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Abstract

An attempt was made to determine foraging strategies of butterflies, foraging time budget, duration of foraging and nectar plants interactions for one year (2015-2016) in a semi-urban forest and urban green habitat. Total thirteen butterfly species were selected to find revealed interspecific variations in time budget of foraging on specific flower, which served as a proxy for pollination efficiency. The *Eurema hecabe* (Pieridae) 390 ± 6.37 and *Tirumala limniace* (Danaidae) 245 ± 1.90 showed highest and lowest foraging time budget was in *Spindasis lohita* (Family: Lycaenidae) 16 ± 1.58. In contrast, *Spindasis lohita* demonstrated the significance foraging with longer duration 389.75 ± 3.73 seconds per visit on *Micromelum minutum*. When the visit numbers of foraging were lower the butterfly usually foraged with a longer duration. *Danaus chrysippus* (Family: Danaidae) was identified as the most significant pollinator with a longer foraging duration (21.3 ± 1.98) on the flower of *Helianthus debilis.* The foraging time budget of this species was varied in different nectar plants. The nectar plants *Lantana camara* was widely used by *Tirumala limniace* (Danaidae), *Pelopides matheas* (Hespiridae) and *Junonia almana* (Nymphalidae). The foraging efficiency on nectar plants was higher those had longer proboscis e.g. *Pachliopta aristolochiae* (15.21 ± 9.92) and *D. chrysippus* (12.45 ± 0.5); had a selective advantage when foraging the nectar plants. The *P. mathias* (8 ± 1.45) and *Lampides boeticus* (7.16 ± 0.5) had shorter proboscis compared to others. The results of this study offers a valuable tool for identifying key pollinators butterfly species. This study will enhance ecosystem services and pollinator conservation planning through preserve the plant species and their interaction with butterfly.

Introduction

The butterflies are thought to be opportunistic foragers and widely recognized as a pollinator of a terrestrial ecosystem. In the forest ecosystem, pollination is essential for a healthy plant population[1-3]. They visit a large range of nectar plant flowers[4].

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There are species-specific flower preferences in butterflies' selection of flowering plants as nectar sources[5]. The choice of flower for foraging depends on innate color and patterns of preferences[4,6]. Butterflies are ecologically important groups of insects showing complex foraging behaviour during searching food and nectar from selective flowering plants[7].

In the morning and evening, the butterflies are typically foraging. Butterfly foraging activities aid in the gene flow of plant populations during feeding and pollen collection because the plant flowers they visit contain entomophilous pollen[8,9]. The composition of the butterfly community varies significantly throughout the seasons than habitats[10,2]. Climate and plant phenology are also important variables that influence butterfly abundances[8,9]. In addition, different flowering plants differ in nectar composition and it varied with seasonal weather and exploitation[7]. Different types of plants are preferred by adult butterflies for feeding[11]. Certain plants support urban and forest green spaces according to the particular needs of the various geographic regions[8]. Understanding the importance of adult feeding for butterfly longevity and reproductive success requires knowledge of feeding behavior and foraging patterns[11,12]. The nectar quality and concentration have an impact on butterfly's longevity and ability to reproduce[2,3,12-14]. Lack of nectar may shorten butterfly life expectancy, decrease fecundity of adults and also increase emigration from breeding grounds[15,16].

Due to varying energy and nutritional requirements as well as their reliance on locally available flora, nectar demands may differ among butterfly species in different habitats[14,17]. The distribution of native butterflies is directly correlated with the floral diversity of an area and they are linked to the dominant local flora[18]. Additionally, they have evolved a variety of host plant preferences that enable them to effectively utilize a range of food sources[19]. Butterflies foraging habits vary widely and influenced by the depth of the corolla and flower clustering[20]. One common ancestor gave rise to the sectorial proboscis of butterfly. The range of flowers from which nectar can be extracted is restricted by the length of the proboscis of butterfly[21]. Another important aspect of foraging is learned behavior[6]. Even though studying butterflies foraging habits has been crucial to understanding their dietary preferences and the variety of nectar plant species they choose as a source of nutrition. However, this topic is still not well understood. Identify the nectar plant species that were needed for a particular management program in order to serve as food sources for butterfly[22]. Additionally, butterflies provide crucial ecological services that maintain global biodiversity. Their mediation of plant-pollinator interactions is crucial to agricultural food production[16]. The information on species-specific foraging behavior represents an important attempt. Field studies that focus on nectar plant preferences, morphological adaptations for foraging, and foraging strategies are essential for understanding the basic behavioral strategies of an individual and populations in response to habitat fragmentation and biodiversity loss[23]. Moreover, butterfly populations are increasingly threatened due to habitat destruction, loss of host plants, environmental pollution, and climate change. Plant-pollinator interactions have been demonstrated to be significant due to the destruction of

invasive alien plant species[22]. Studies on butterfly foraging strategies and interactions with nectar plants are smaller in magnitude and have only been conducted in some forest areas of Bangladesh[24-27].

The comparative studies on foraging strategies of adult's butterflies at different family level have never been a subject earlier. Despite this comparative studies on time budgets, pollination efficiency, and proboscis length are limited, revealing a dire need for more intensive research on foraging strategies. Therefore, in the present study, the butterfly's species-specific nectar plants association and respective foraging behavior have been investigated in a semi-urban and urban area. We aimed to clarify the strategies of foraging in different butterflies at the family level to understand species-specific response and secondly to examine the variation of proboscis length and their interactions with nectar plants.

Materials and methods

Study area and period: To investigate the foraging strategies of butterflies and their interactions with nectar plants during feeding select different types of habitats. These study areas were the Butterfly Research Park of Bhawal National Park located in the Gazipur district (latitude 23° 46′37.66″ N and longitude 90° 23′58.14″ E), Botanical and Zoological Gardens (latitude 23° 72′68.99″ N and longitude 90° 40′15.42″ E) of Curzon Hall, University of Dhaka. The study was conducted for one year from May, 2015 to April, 2016. The observation was conducted weekly in every ± 5 days from the morning 10:00 to the afternoon 16:30 in time of the peak activities of foraging and it was depending on the weather.

Experimental procedure: The butterflies around the observation sites were tracked while they were foraged and recorded visually with respect to their family level. Total thirteen species of butterflies from six families were selected to evaluate the foraging strategies in the field conditions. Butterflies species were selected based on species availability during the study period. The selected species were *Eurema hecabe, Eurema simulatrix, Leptosia nina* (Pieridae); *Pachliopta aristolochiae, Papilio polytes* (Papilionidae), *Junonia almana, Junonia atlites* (Nymphalidae) *Pelopidas mathias*, *Pelopidas agna* (Hesperiidae), *Tirumala limniace*, *Danaus chrysippus* (Danaidae), *Lampides boeticus* and *Spindasis lohita* (Lycaenidae) were identified according to their external morphology and taxonomic keys[1]. Captured photographs of the selected butterflies were also observed for final taxonomic identification. The foraging behavior of selected butterflies were conducted by maintaining a distance at least 1m from the selected transects to avoid disturbances. The flowering nectar plants on either side of the selected transects were observed (within 3 m) those were visited by butterflies[26,27]. The nectar plants those were used in the foraging were identified and recorded to evaluate the interactions of butterflies with their preferred nectar resources.

Observation of Foraging behavior: The foraging behavior of butterflies was observed along a fixed transect route walk during the field study to record the feeding behavior of butterflies[27]. The foraging behavior of an individual or specified group of individuals were recorded[26,28]. Foraging activities were recorded by a Sony DSC-W710 digital camera. The captured photograph and video of butterflies were contributed with visual records for analysis of foraging activities.

Observation of foraging time budget: The foraging time budget of selected butterflies on nectar plants during walks around the study areas was observed. The total number of visits and the length of time spent by each of the specified butterflies had been recorded during the study period. A time frame (150 minutes,) the numbers of total visit and the duration of foraging was made ranging from 0-5, 6-11, 12-17, 18-23, 24-29, 30-35, 36-41, 42-47, 48-53 and 54-59 seconds. The total number of visits was counted based on this time frame during the study period (Table 1).

Table 1. Foraging behaviour of the butterflies on their host plants in relation with time

Time Frame	Foraging behavior and Types
0-5 second	Quick, transient visits, may indicate low nectar availability, flower inspection, or high mobility
6-11 second	Balanced foraging, likely extracting nectar efficiently, good contact with reproductive parts of flower
12-29 second	Moderate Prolonged feeding, higher chance of pollen contact and transfer
More than 30 second	Rare with prolonged energy-intensive foraging behavior, interactions with richer nectar sources

Evaluation the pollination status of butterflies: The pollination status of selected butterflies was classified into three categories on the basis of their visit numbers on the related foraging plants. The categories were based on the frequency of visits during a 150-minutes (2.5-hour) observation period. The categories were: category 1: species those visited more than 200 times; category 2: species visited 100–200 times and category 3: species visited fewer than 100 times.

Observation of the nectar plants: In study areas, observations of butterflies foraging on related plants were recorded. Along and within the transects all butterflies with flowering nectar-producing plants were recorded only if a butterfly definitely probed a flower[29-31]. A data set was generated that contained the nectar plants which every butterfly visited while foraging[32,33]. The frequency of visits by different butterflies to the same plant (*Lantana camara*) and the butterfly that used different plants as a nectar source was also examined. For this purpose, *Junonia almana* and *Junonia atlites* of the family Nymphalidae, *Tirumala*

limniace of the family Danaidae, and *Pelopidas mathias* of the family Hesperiidae were selected.

Proboscis length measurement: A sweeping net was used to catch selective butterfly species to examined the external body color and the length of proboscis. A needle was placed into the coiled part of the proboscis of live butterflies, and the proboscis was straightened out as soon as it was captured to measure its length. The shorter proboscis of smaller butterflies was measured after they died. The Bioblue lab microscope (BB.1152-PL model) with a millimeter scale was used to measure the length of the proboscis. The proboscis length was determined by measuring the space between the base of the labial pulps and the tip of the proboscis.

Data analysis: The number of foraging was calculated by the total number of visits by the butterfly in different seasons, with the standard error of a mean value was analyzed. The foraging numbers of all selected butterflies were calculated during the study period. The calculated minimum and maximum foraging duration were separately for each butterfly considered as a response of butterfly to the nectar plant. The means of foraging duration was also calculated with standard error value, was analyzed by using Microsoft Excel 2007. The data on the length of proboscis were evaluated by analysis of variance (ANOVA) and followed the post-hoc Tukey-Kramer method to separate the means ($a = 0.05$). All analyses were performed by the Tukey HSD test with significance of ($P < 0.005$) by using PAST software.

Results and Discussion

The results revealed that feeding habit and foraging behavior of butterflies were found to be very significant in their life cycle. Foraging behaviour helps in taking energy directly from the nectar plants, especially from the flowers. The *Eurema simulatrix* (Pieridae) was a medium size butterflies prefers to visit the flowers of *Petunia hybrida* for foraging. The foraging time budget of this butterflies was 9.36 ± 4.6. The minimum duration of foraging was 3 seconds and the maximum was about 17 seconds (Table 2). This butterfly visited the *P. hybrida* around 140 ± 1.76 times during the observation period. It has been found that *E. simulatrix* is the highest visited about 60 times and forages around 6-11 seconds it indicated they are balanced foraging butterfly (Fig. 1).

The total visited times indicated this butterfly was a significant pollinator. Foraging was frequently observed by a single species in a variety of patterns and postures on various flowers e.g. *Cethosia cyane, Mikania cordatum* and *Duranta repens* when used as nectar plant. The foraging behavior varied from flowers to flowers it depending on color and odors of flowers. It provides specific information to butterfly to change the flowers. Butterflies spread pollen from one flower to another in order to feed and was vital to the plant's gene flow[31,34]. The primary food source for butterflies consists of nectar from flowers[20].

Table 2. Butterfly species and their interactions with foraging plants, number of foraging and duration of visits

Butterfly Family	Butterfly Species	Foraging nectar plants	Total number of foraging ± SE	Foraging Duration min (Second)	Foraging duration max (second)	Foraging duration Av ± SE (second)
Pieridae	*Eurema simulatrix*	*Petunia hybrida* (F: Solanaceae)	140 ± 1.76	3	17	9.36 ± 4.6
Pieridae	*Eurema hecabe*	*Oxalis corymbosa* (F: Oxalidaceae),	390 ± 6.37	1	19	8.85 ± 5.6
		Spilanthes calva (F: Asteraceae)	112 ± 2.12	1	29	11.21 ± 9.04
Pieridae	*Leptosia nina*	*Vernonia cinerea* (F: Asteraceae)	165 ± 5.15	1	21	6.06 ± 5.19
Nymphalidae	*Junonia atlites*	*Cosmos sulphureus* (F: Asteraceae)	66 ± 3.56	1	20	8.82 ± 5.46
Nymphalidae	*Junonia almana*	*Lantana camara* (F: Asteraceae)	114 ± 1.58	3	45	13.42 ± 1.18
		Cosmos sulphureus (F: Asteraceae)	91 ± 1.56	1	26	9.62 ± 7.21
Papilionoidae	*Pachliopta aristolochiae*	*Bougainvillea glabra* (F: Nyctaginaceae)	170 ± 0.70	3	24	10.82 ± 13.18
Papilionoidae	*Papilio polytes*	*Plumbago zeylonica* (F: Plumbaginaceae)	210 ± 4.50	1	12	3.67 ± 3.53
Hesperidae	*Pelopidas agna*	*Wedelia trilobata* (F: Asteraceae)	160 ± 2.46	1	11	4.94 ± 3.07
Hesperidae	*Pelopidas mathias*	*Lantana camara* (F: Verbenaceae)	140 ±2.54	3	17	9.36 ± 4.56
Danaidae	*Tirumala limniace*	*Lantana camara* (F: Verbenaceae)	245 ± 1.90	1	14	5.57 ± 3.42
Danaidae	*Danaus chrysippus*	*Helianthus debilis* (F: Asteraceae)	200 ±3.66	2	53	21.3 ± 1.98
Lycaenidae	*Lampides boeticus*	*Helianthus debilis* (F: Asteraceae)	180 ±3.80	2	21	10.83 ± 2.20
Lycaenidae	*Spindasis lohita*	*Micromelum minutum* (F: Rutaceae)	16 ± 1.58	118	900	389.75 ± 3.73

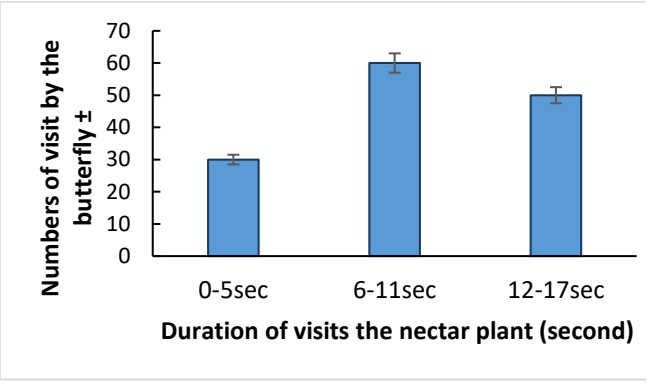

Fig. 1. Foraging time budget of *Eurema simulatrix* (F: Pieridae) on nectar plant *Petunia hybrida*.

The foraging strategies of *Eurema hecabe* was varied from *Eurema simulatrix* indicated species specific interactions with nectar plants, and had different foraging strategies. *E. hecabe* was visited *Oxalis corymbosa* 390 ± 6.37 times within 150 minutes of the observation period. It spends a maximum 19 and a minimum 1 second foraging on the flowers of *O. corymbosa*. The time budget of *E. hecabe* for foraging was 8.85 ± 5.6. The number of total visit was higher indicated this butterfly played significant role pollinator (Table 2). This species also preferred *Spilanthes calva* (F: Asteraceae) as a nectar plant and visited 112 times. The maximum foraging duration was 29 seconds. The time budget was 11.21 ± 9.04. On *S. calva*, the highest visit was 48 times for 0-5 seconds duration, while the lowest visits happened 12 times for 6-11 seconds (Fig. 2). These patterns suggest that while high visit frequency is important, prolonged contact time may be a stronger predictor of pollination quality. When butterfly comes to identifying and selecting flowers, visual indicators such as flower size and shape can be important[35]. One of the primary factors that limits the kinds of visitors that can pollinate flowers is the shape of the flower. compared to open flowers, tubular flowers displayed a higher abundance of butterflies[18].

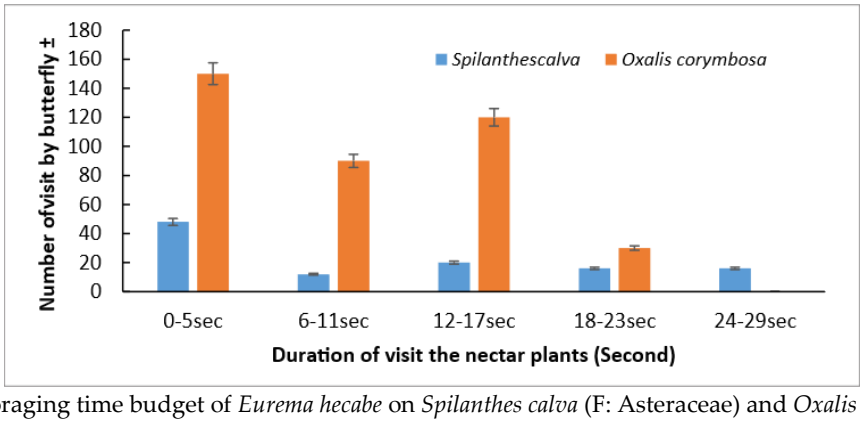

Fig. 2. Foraging time budget of *Eurema hecabe* on *Spilanthes calva* (F: Asteraceae) and *Oxalis corymbosa* (F: Oxalidaceae).

The *Leptosia nina* (Pieridae) has been found to visit *Vernonia cinerea* about 165 ± 5.15 times. It foraged for a maximum of 21 to a minimum 1 second. *L. nina* spent its time budget of 6.06 ± 5.19 feeding on *V. cinerea* blooms (Table 2).

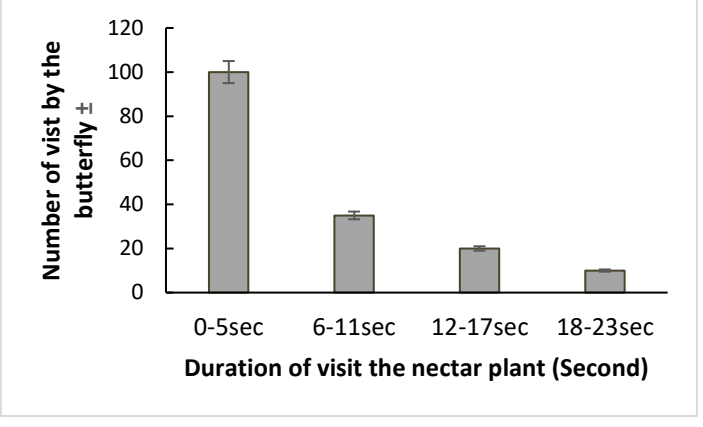

Fig. 3. Foraging time budget of *Leptosia nina* (F: Pieridae) on *Vernonia cinerea* (F: Asteraceae).

The results revealed that this butterfly visited highest 100 times for short duration of 0-5 seconds and lowest 10 times for intermediate duration of 18-23 seconds (Fig. 3). The insect's mobility, which in turn speaks of how well they can able to use the floral resource, can be assessed by the number of flowers visited per unit of time and the period of time spent at the flowers. It is readily apparent that butterflies compete with one another for nectar resources[36]. The results of the present study indicated that the members of Family Nymphalidae (*Junonia atlites*) made 66 ± 3.56 visit to *Cosmos sulphureus* for foraging. On the *C. sulphureus* flower, it spends 1 to maximum 20 seconds. When foraging on *C. sulphureus* blooms, *J. atlites* time budget was 8.82 ± 6.46 (Table 2). This butterfly visited 30 times for of short duration (0 to 5 seconds). However, longer and medium foraging durations of 6-11, 12-17 and 18-23 second, nectar collection happened ten times (Fig. 4) indicated they are efficient pollinators and the nectar plants contained a low amount of nectar[21].

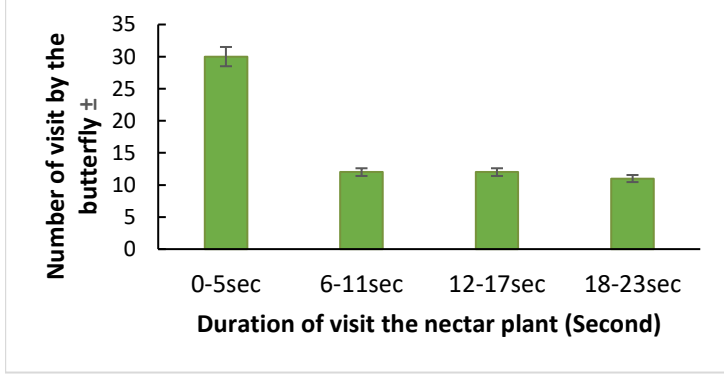

Fig. 4. Foraging time budget of *Junonia atlites* (F: Nymphalidae) on *Cosmos sulphureus* (Asteraceae).

On the other hand, the *Junonia almana* selected *L. camara* for foraging as a nectar plants about 114 ± 1.58 times. This butterfly foraged for a maximum of 45 seconds and a minimum of 3 seconds. Foraging time budget on this flower was 13.42 ± 1.18 (Table 2). The results also revealed that within 150 minutes, *J. almana* made foraged on the *L. camera* about 42 times for 6-11 seconds duration and 91 visits to *C. sulphureus*. The period allotted to *J. almana* for foraging was 9.62 ± 7.21. On *C. Sulphureus*, the most visits took place 36 times for 0–5 seconds (Fig. 5). This butterfly was not foraged on *L. camara* and *C. sulphureus* at the same time and the foraging was varied in duration. It depended on the nectar quality[22,29].

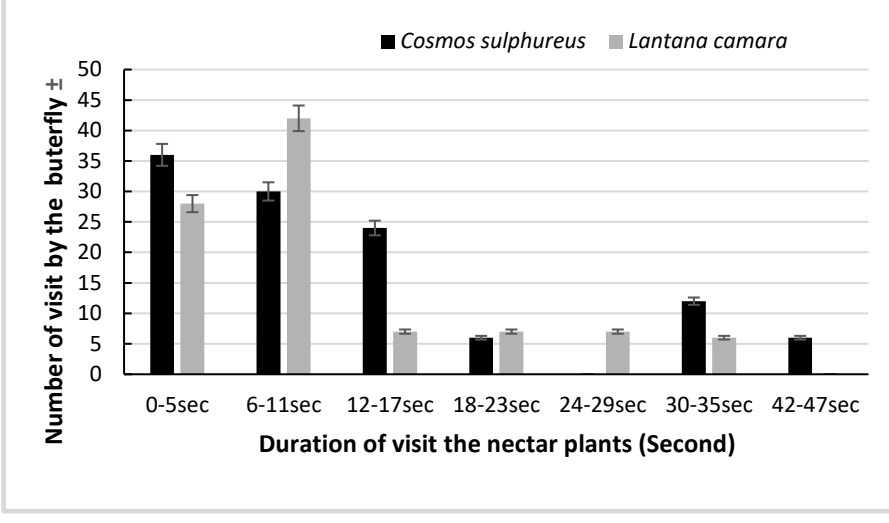

Fig. 5. Foraging time budget of *Junonia almana* (F: Nymphalidae) on *Cosmos suphureus (F: Asteraceae)* and *Lantana camara* (Asteraceae).

The nectar flower selection influenced the butterfly biology, including flight cost and energy intake rate[32]. This implies that in order to maximize benefits (energy intake) relative to energy consumption, pollinators must make sustainable decisions about what types of flowers they visit[25]. The *Pachliopta aristolochiae* (Papilionidae) has been found to forage *Bougainvillea glabra* about 170 ± 0.70 times in the period of observation. The blossom of *B. glabra* was foraged upon for 5 to 24 seconds. The *P. aristolochiae* was foraged the least 10 times for 24-29 sec duration (Fig. 6). The time budget was 10.82 ± 13.18. Since it has had 60 times visits for about 6-11 seconds considered as a significant pollinator (Table 2).

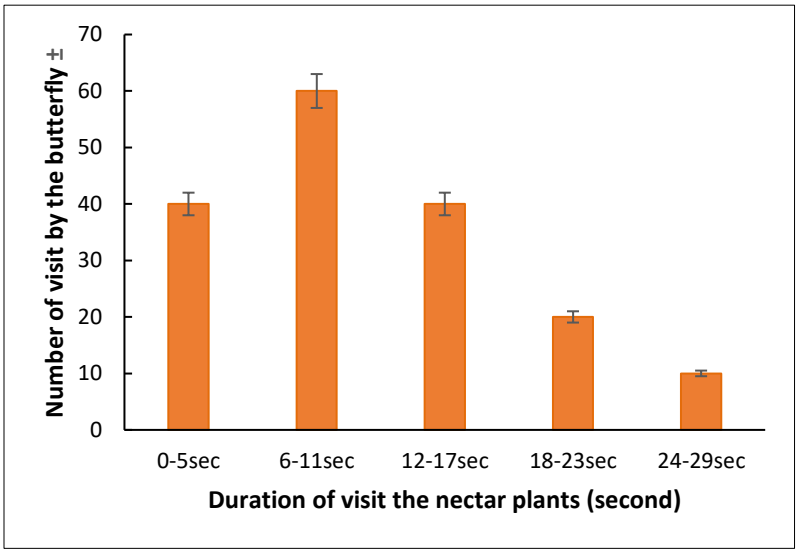

Fig. 6. Foraging time budget of *Pachliopta aristolochiae* (F: Papilionidae) on *Bougainvillea glabra* (Nyctaginaceae).

Papilio polytes (Papilionidae) was sighted visiting on *Plumbago zeylanica* for foraging about 210 ± 4.50 times and considered as a highly significant pollinator. This species spends foraging about 1 seconds to maximum of 12 seconds. On the *P. zeylanica*, *P. polytes* time budget was 3.67 ± 3.53 (Table 2). This butterfly visited between 0 and 5 seconds indicated had short duration foraging capacity and between 12 and 17 seconds, foraged the least (10 times) (Fig. 7).

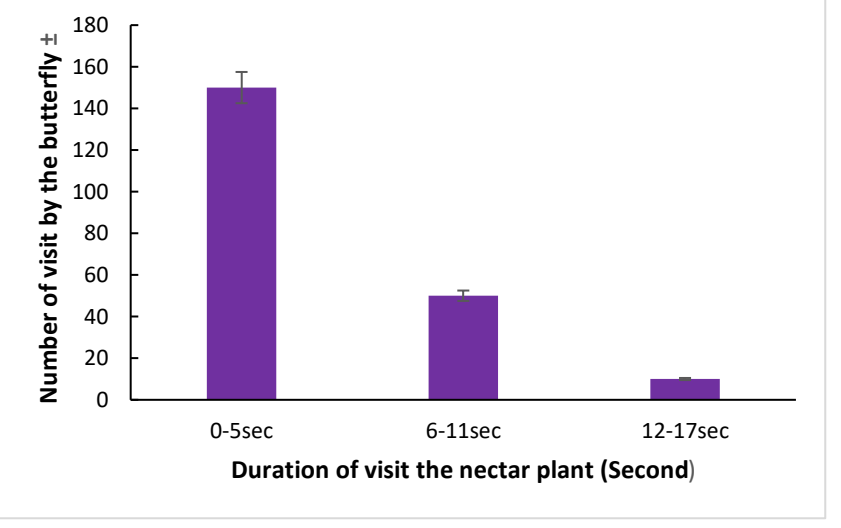

Fig. 7. Foraging of *Papilio polytes* (F: Papilionidae) on *Plumbago zeylanica* (Plumbaginaceae).

The length of time spent is varied among species and the time spent by the same species on different plants also differs[21]. *Tirumala limniace* (Danaidae) also selected *L. camara* as a source of nectar and a total 245 times foraged within 150 minutes. It spends a maximum of 14 seconds on this plant. *T. limniace* spends 5.57 ± 3.42 of its time budget for feeding on the blooms of *L. camara*. Since it has been visited 245 ± 1.90 times, it has transferred pollen 245 times, considered as an efficient pollinator on February. The largest number of butterfly visits (140) occurred within 0 to 5 seconds, while the lowest number (20) occurred between 12 and 17 seconds (Table 2 and Fig. 8). The length of foraging visits relates to the amount of accumulated nectar. When nectar is scarce, butterflies visit many flowers briefly. When nectar is abundant, they spend more time per flower but visit fewer[27].

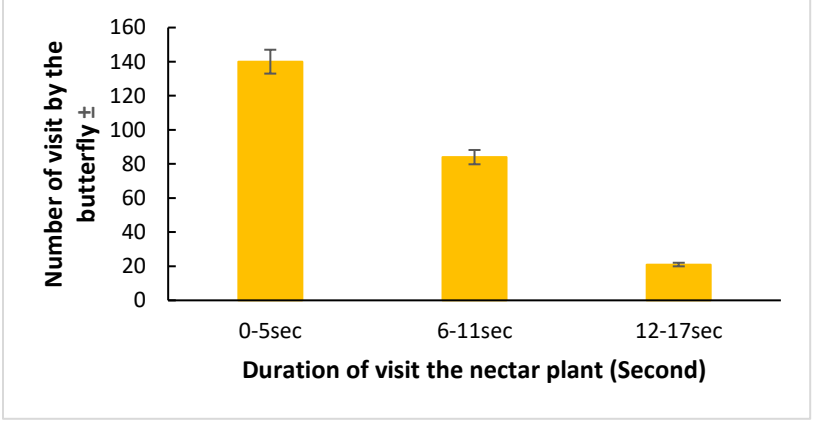

Fig. 8. Foraging time budget of *Tirumala limniace* (F: Danaidae) on *Lantana camara* (Verbenaceae).

It has been observed that *D. chrysippus* visited 200 times on *Helianthus debilis* within 200 ± 3.66 seconds. It spends a maximum 53 seconds on a flower of *H. debilis*. The time budget of *D. chrysippus* for its foraging was 21.3 ± 16.98. It foraged 200 ± 3.66 times and was considered as a highly significant pollinator in the month of March. This butterfly showed the highest range of foraging. It has been found that this butterfly visit of highest 50 times for 0 to 5 seconds, and the lowest was 10 times within 24-29 and 30-35 seconds (Table 2 and Fig. 9).

In plant-butterfly interactions, proboscis length has an important role in foraging efficiency, resource partitioning and pollination. Most adult butterflies feed on nectar and participate in pollination[37]. During foraging butterflies need to locate and consume resources (flowering plants), balancing the energy spent in foraging with the gained energy of nectars. This balance between foraging and energy spends depends on nectar plants availability, competition for foraging when using the same nectar plants for foraging in a similar habitat[38].

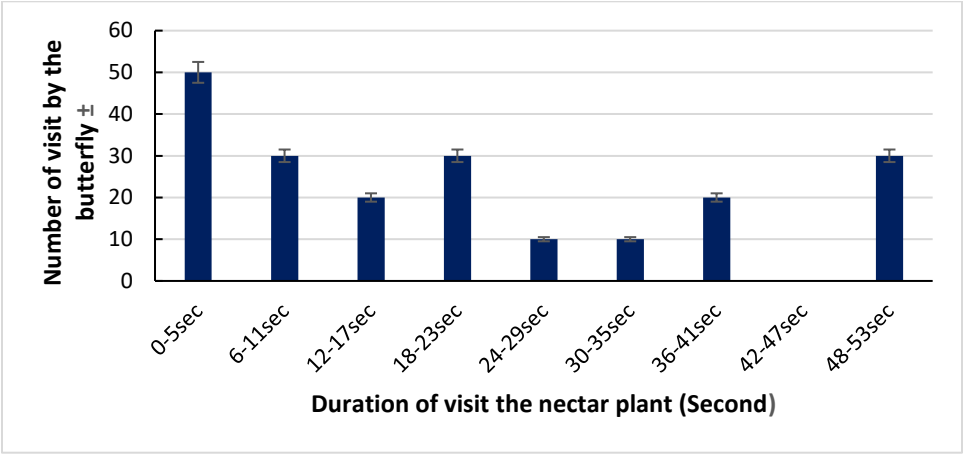

Fig. 9. Foraging time budget of *Danaus chrysippus* (F: Danaidae) on *Helianthus debilis* (Asteraceae).

It has been observed that, *Pelopidas agna* (Hesperidae) visited 100 times on *Wedelia trilobata*. It forages on a *W. trilobata* flower for a maximum of 11 seconds and a minimum of 1 second. The time budget allotted to *P. agna* feeding on *W. trilobata* blooms was 4.94 ± 3.07. It spreads pollen 100 times in 0-5 seconds because the plant has been visited 100 times, making the butterfly species a significant pollinator while the lowest 60 times foraged for 6-11 seconds (Table 2 and Fig. 10).

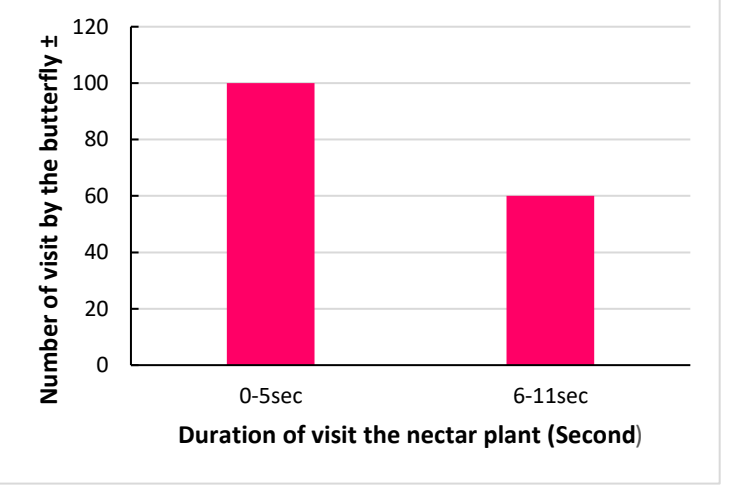

Fig. 10. Foraging time budget of *Pelopidas agna* (F: Hesperidae) on *Wedelia trilobata* (Asteraceae).

It has been observed that *Pelopidas mathias* (Hesperidae) visited on *L. camara* about 140 times during the observation period indicated this butterfly was a significant pollinator. It spends no more than 17 seconds on a blossom of *L. camara*. This butterfly's speeded time budget was 9.36 ± 4.56 feeding on the flowers of *L. camara*. The maximum 60 butterfly visits

occurred within 6 to 11 seconds, whereas the lowest 30 visits occurred within 0-5 seconds (Table 2 and Fig. 11). Morphological differences in body size and proboscis length of butterfly may lead to niche segregation and specialization[36,39,40]. Similar to this, within-population variation can lead to speciation and differences in food exploitation[10].

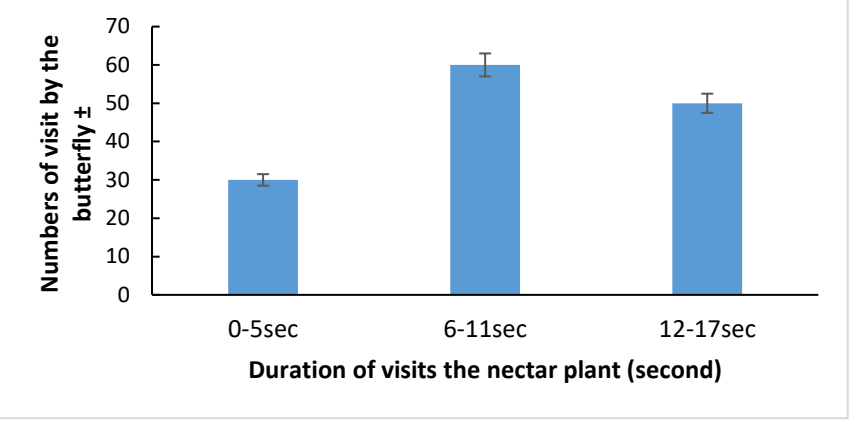

Fig. 11. Foraging time budget of *Pelopidas mathias* (F: Hesperidae) on *Lantana camara* (Verbenaceae).

The *Lampides boeticus* (F: Lycaenidae) was recorded to forage on *Helianthus debilis* (E: Asteraceae) a total of 180 ± 3.80 times over a 150-minutes observation period. The butterfly spent between 2 and 21 seconds on individual flowers, with an average foraging duration of 10.83 ± 6.20 seconds (Table 2).

Given the number of visits, it is presumed to have facilitated pollen transfer 180 times. Due to its frequent visits and efficient foraging behavior, *L. boeticus* was regarded as a significant pollinator of *H. debilis*. The majority of its visits occurred within the 0–5 second and 6-11 seconds intervals, with each category accounting for 50 times of visits which was the highest recorded in the study (Fig. 12).

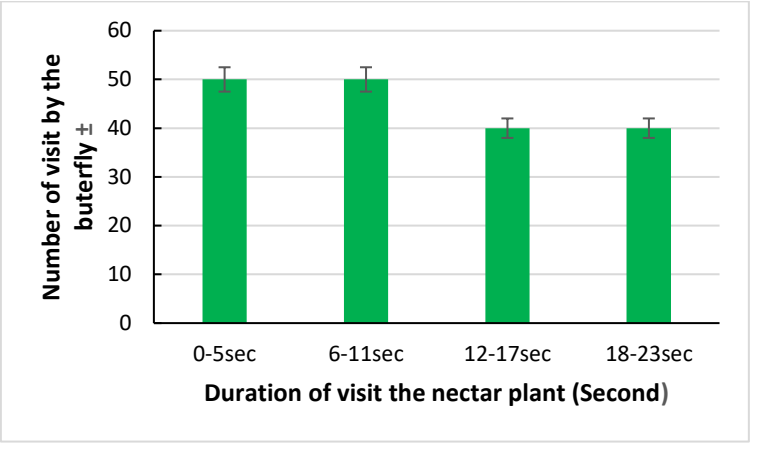

Fig. 12. Foraging time budget of *Lampides boeticus* (F: Lycaenidae) on host plant *Helianthus debilis* (Asteraceae).

It was observed that *Spindasis lohita* (F: Lycaenidae) visited *Micromelum minutum* flowers 16 times over a period of 150 minutes. The butterfly spent highest maximum duration of about 900 to 118 seconds on the flower. The average time spent per visit (time budget) was 389.75 ± 230.73 seconds. Butterfly frequently had species-specific flower preferences and did not choose flowers at random when collecting nectar. One characteristic of flower constancy was learned behavior[6,40]. However, due to its relatively low visitation frequency and prolonged foraging duration, *S. lohita* can be considered a less significant pollinator of *M. minutum*. From the observation, it has been analyzed that all the butterflies' foraging time frames were within 0-59 seconds and none of them crossed that limit (Table 2 and Fig. 13).

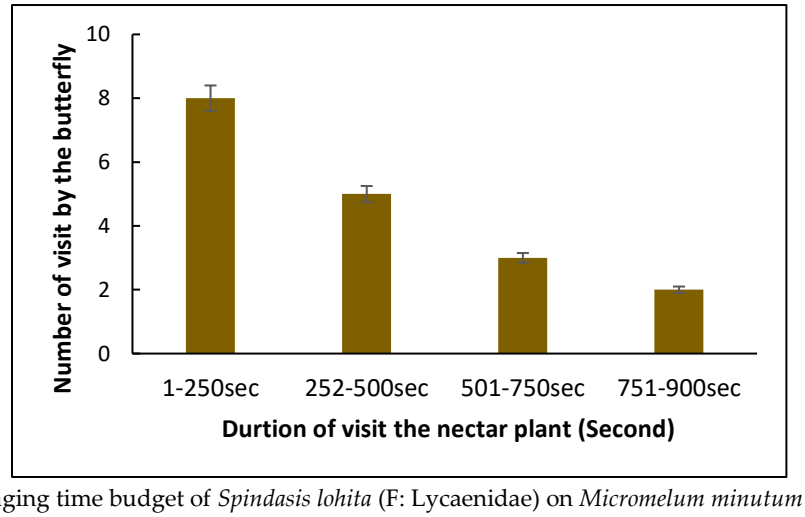

Fig. 13. Foraging time budget of *Spindasis lohita* (F: Lycaenidae) on *Micromelum minutum* (Rutaceae).

The availability, diversity and spatial arrangement of nectar plants influence butterfly abundance, movement and population dynamics. This may enhance seed-set due to increased pollen transfer during longer visits. Bushes (small herbs, shrubs, and grasses) are important for maintaining biological diversity in various plant aggregates[19,41]. The resources of pollen or nectar in a natural habitat alter through time and space.

Foraging time budget of different butterflies on the same nectar plants

The present results revealed that butterfly species from different family's showed variations in their foraging behavior when using the same nectar plant (*L. camara*) in same habitat. Observations revealed that the foraging strategies of *J. almana*, *T. limniace* and *Pelopidas mathias* was differed significantly within the same time intervals. The highest number of visits by *T. limniace* (140 times) occurred for short duration and showed the second highest number of visits (84 times). *P. mathias* had lower number of visits with medium to prolonged durations (6–11 seconds and 12-17 seconds). *J. almana* was a lowest visitor with a medium prolonged duration forager among these three species on a same nectar plant (Fig. 14). These results indicate that even within the same time frame and on the same plant, behavioral differences and energy requirements were evident among these butterfly species from different families.

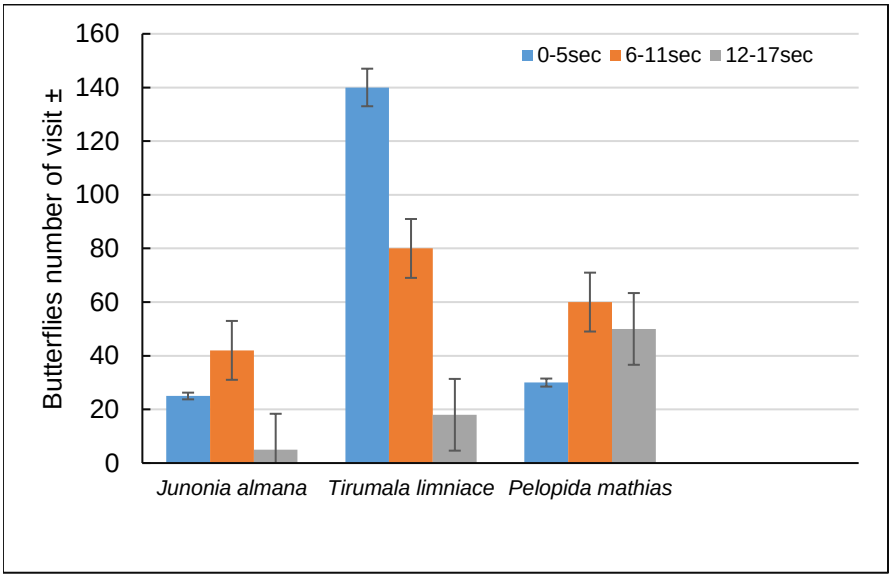

Fig. 14. Foraging time budget of *Junonia almana* (F: Nymphalidae), *Tirumala limniace* (Danaidae) and *Pelopidas mathias* (Hesperiidae) on *Lantana camara* (Verbenaceae).

The mouthpart length was one of the most important morphological features for flower-visiting insects. On the one hand, through size incompatibility, nectarivores with short mouthparts are not allowed to consume deep flowers. Because viscous liquids need

more force to imbibe through longer tubes, species with long mouthparts may not be able to reach shallow flowers due to their high nectar viscosity[17,35,42]. Butterflies spend their time and energy to increase foraging opportunities and gather resources elsewhere in order to pay for information gathering. In insect pollinators, variations in mouthpart length and corolla length might impact pollination, resource partitioning, feeding efficiency, and flower selection[43-45]. Butterflies like to perch on larger flower heads when they hunt nectar, collecting pollen on their legs and bodies as they search for food. The legs and the butterfly's proboscis are longer and further away from the flower's pollen so less pollen collects on its body parts than it does on bees, but still, they are very effective[46-50].

Proboscis length variation and foraging strategies

The members of family Papilionidae (*P. aristolochiae*) had larger proboscis (15.21 mm ± 9.92) followed by Danaidae (*D. Crypsippus*) had (12.5 mm ± 0.5). The proboscis morphologies relate to foraging range. Differences among or within species may result in resource partitioning and speciation. The members of the family Hespiridae and Lycaenidae processed smaller proboscis (7.16 mm ± 1.5 to 8.12 mm ± 1.25) in related the size of their nectar plants (Fig. 15). Proboscis length act as a strong predictor for access of the flowers and wing structure of butterflies was considered as a factor suitable for exploitation of the flowers. For nectar feeding, adults butterflies those possess long proboscis can feed on flowers with deeper corolla. The butterflies with short proboscis restrict their feeding to flowers with shallow corolla tube. Corolla depth was another key factor that limited exploitation by nectar feeding butterflies[21,51].

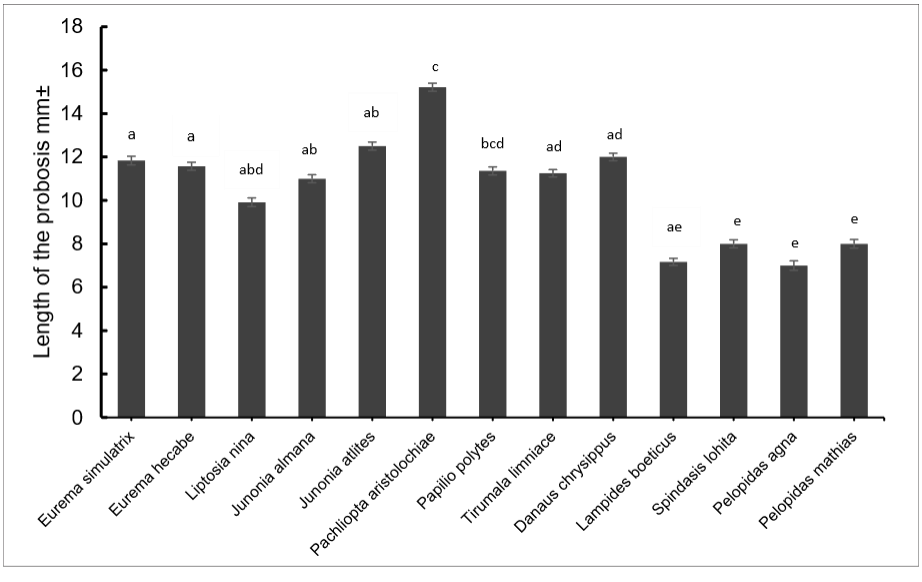

Fig. 15. The variation the proboscis length among selected family members of butterfly. Different letter above the bar indicated significant difference ($P < 0.05$) among the size of proboscis.

Large-bodies butterflies with larger wing required richer, plenty of food and process a larger proboscis for assessing a wide range of flowering plants. The proboscis length, body mass and wing expanse was positively correlated with foraging efficiency defined as the handling time of foraging[30,52-56]. The foragers need to make complex foraging decisions on which nectar plants to select, where to forage, and for how long to forage. Butterflies gain information from foraging and exploring the environment. Learning behavior provides a way for foragers to track the changes in environmental conditions. In general, butterflies have specific habitat and nectar requirements to maximize net energy gain during foraging[57-59]. Moreover, certain butterfly species are polyphagous thus helping them to adopt to live in diversified habitats[60].

Conclusion

The majority of butterfly species exhibited the highest number of visits the flowers of 0-5 second time frame, indicating a general tendency toward quick nectar foraging. However, key pollinators are *D. chrysippus*, *S. lohita and L. boeticus* demonstrated different foraging durations and exceeded 20 seconds per visit, which is likely to enhance pollen transfer efficiency. Analyzing time spent per flower and total visitation rates will helps to estimate butterfly species contribution in pollination. Such, behavioral metrics are essential for identifying key pollinators in fragmented habitats which could serve in the management and conservation actions of the plant and butterfly species. By understanding butterfly foraging strategies, this study will provide a scientific foundation for supporting pollinator conservation efforts and their host and nectar plants promoting sustainable plant-pollinator interactions that serve as essential foraging and breeding grounds in Bangladesh.

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