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POLLINATOR DIVERSITY AND PLANT-POLLINATOR INTERACTIONS IN THE PUTHIA UPAZILA OF RAJSHAHI DISTRICT, BANGLADESH

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Abstract: From September 2021 to August 2022 a study was carried out to assess the species diversity and abundances of pollinators and plant-pollinator interactions in Puthia Upazila of Rajshahi District, Bangladesh. A total of 3284 individuals were recorded, in which 109 species of 87 genera were identified as belonging to 49 families and 12 orders under three classes (Insecta, Aves and Mammalia). The relative abundance of insects and non-insect pollinators was 91.57% and 8.43%, respectively. A maximum of 32 species (relative abundance, RA= 32.70 %) was observed in the order Lepidoptera and minimum in the order Chiroptera (1 species; RA= 0.09 %). The most abundant family was Apidae (n= 267, RA= 8.12%) and the most dominant species was *Eurema hecabe* (n= 95, RA= 2.89%) (Family: Pieridae, Order: Lepidoptera). Based on number of individuals (n), the status of pollinators: 25 species were very common, 29 species were common, 18 species were fairly common, 21 species were rare and 16 species were very rare. A total of 51 flowering plants were documented that were visited by the pollinators, of which 32 were crop plants and 19 were non-crop flowering plants. Among them, the flowers of Orangeberry (*Glycosmis pentaphylla*) received the greatest number of pollinator species, i.e., 55. Overall, 79 species of recorded pollinators visited non-crop flowering plants, 65 species visited crop plants, and 35 species were common in both. According to the obtained individuals, the Shannon (H') and Simpson (1-D) diversity indices were 4.41 and 0.99, respectively. The Berger-Parker dominance (d) and Pielou's evenness index (J') were 0.03 and 0.94, respectively, while the Margalef (D_{Mg}) and Menhinick (D_{Mn}) species richness indices were 13.34 and 1.90, respectively. The present study is the first report to offer baseline abundance and diversity of main pollinator groups in agroecosystems and provide data for a checklist of the variety of pollinators in the Puthia Upazila, Rajshahi, Bangladesh.

Key words: Species Diversity, Pollination, Pollinators, Flowering Plants, Plant-Pollinator Interactions

INTRODUCTION

The mutual interactions between pollinators and flowering plants create not only plant diversity but also the diversity of about 3,50,000 animal species,

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including insects, birds, and mammals (Bond 1994, Ollerton 2017). Pollinators play an important role in pollinating numerous crops used as human food (Delaplane and Mayer 2000, Potts *et al.* 2010). For maximum yields, 70% of the most widely cultivated crops in the world depend on animal pollinators, and animal pollination is responsible for around 35% of the world's agricultural yield (Klein *et al.* 2006). About 85% of the world's flowering plants rely on animals, primarily insects, for pollination (Ollerton *et al.* 2011). Roughly 73% of the world's agricultural crops are pollinated by certain kinds of bees, 19% by flies, 6.5% by bats, 5% by beetles, 5% by wasps, 4% by butterflies and 4% by birds, indicating that the majority of plant species are dependent on insects for the pollination (Sima *et al.* 2014). According to the Food and Agricultural Organization (FAO) of the United Nations, 90% of the food consumed by the people of 146 countries is produced by about 100 crop varieties, 71 of them pollinated by bees. In contrast, butterflies, moths, thrips, and wasps pollinate the remaining crops (FAO 2007). Beside crop plants, other non-crop flowering plants also harbour many insect pollinators suggesting the significance of wild flowers for the conservation of pollinators (Choi *et al.* 2015).

Plant-pollinator interactions are complex and multifaceted, shaped by the co-evolutionary dynamics between plants and their pollinators. Animal-assisted pollination plays a significant role in most land-based ecosystems serving a key ecosystem service essential for the maintenance of both wild and cultivated plant communities because most angiosperms are pollen-limited and depend on animals for their reproduction (Albrecht *et al.* 2012). A wide variety of species of insects that pollinate plants have coevolved with plants, resulting in biodiversity and productive landscapes (Wojcik 2021). However, various factors, including the availability of floral resources, climatic conditions, land use changes, and the presence of invasive species, can influence these interactions (Dicks *et al.* 2016, Potts *et al.* 2010).

Despite the evidence of importance of pollinators, farmers are little concerned about wild pollinators and have poor insights about the ecosystem services they provide, particularly in underdeveloped countries (Ali *et al.* 2020). A majority of farmers in Bangladesh are illiterate and have no idea about pollination. Because of their ignorance, farmers improperly, carelessly, and unscientifically apply pesticides, preventing a wide variety and abundance of pollinating insects. Emerging nations like Bangladesh must understand the interaction between flowering plants and flower-visiting animals to improve their food security, environment, and economy. Due to the lack of previous investigations in this area, the current study was designed to observe, identify, and record pollinating species on various crops grown in agroecosystems and non-crop flowering plant species close to the area Puthia Upazila of Rajshahi District in Bangladesh.

MATERIAL AND METHODS

Study Area: The study area, Puthia Upazila, is located between latitude 24^0 21' to 24^0 24' north and longitude 88^0 41' to 88^0 50' east in the Rajshahi district of Bangladesh, and the area has a tropical wet and dry or savanna climate (Fig. 1). The district's yearly temperature is 29.03^{0}C (84.25^{0}F), typically receiving about 96.73 millimeters (3.81 inches) of precipitation.

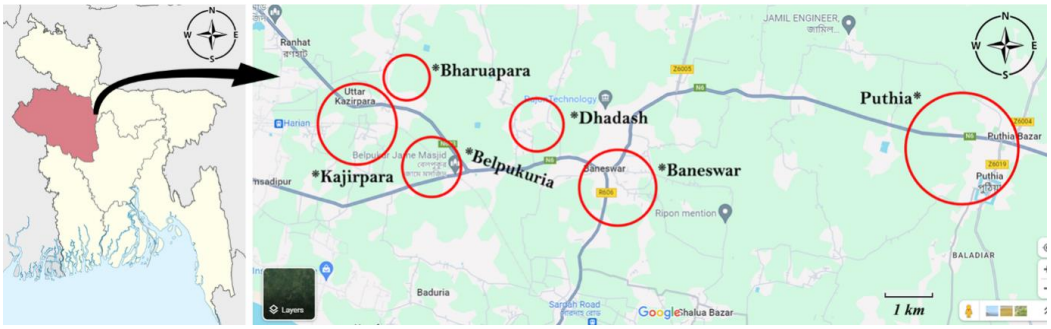

Fig. 1. Map of the study area (Puthia Upazila of Rajshahi District, Bangladesh). 'Sampling Frequency' heading for 'Three sampling sessions … (5.30- 630 pm)'.

Three sampling sessions (January to April, May to August and September to December) were conducted depending on the flowering period of the crop and non-crop plants in the study area. From September 2021 to August 2022, weekly observations and collections of the animal visitors to various flowering plants were done. Sampling took alternating days between 9:00 and 12:00 in the morning and 3:00 and 5:00 in the afternoon. Occasional visits to the habitats were done in the morning (7:00-8:00 am), noon (1:00-2:00 pm) and evening (5:30-6:30 pm).

Observation, Collection, Curing, Stretching and Preservation: The flower visitors of various crops and non-crop flowering plants were observed and collected from five different sites of Puthia Upazila *viz.* Puthia, Baneswar, Dhadash, Belpukuria, Kajirpara, and Bharuapara. Three study methods were utilized to assess the diversity of pollinators: sweep netting, trapping (mostly used for bee diversity) and direct observation (for butterflies and vertebrates' diversity). Insects were collected by a sweeping net (30 cm diameter net with 1.5 mm mesh attached to a 2 m long pole). The insects obtained through the methods described above were transported to killing bottles. 3-4 cotton balls soaked in 2% chloroform were placed inside the glass jars to kill them. Large winged insects were pinned after stretching in insect boxes for dry preservation, while the smaller insects were preserved in glass vials filled with 70% alcohol.

Specimen's number were written down and stored at room temperature. While non-insect pollinators such as birds and mammals were not captured in this study. They were observed and photographed approximately 20-30 meters away from their presence on the flower.

Identification of the Specimens and Documentation: Identification of some collected and observed insect species was done by the examination of their morphological characters according to Borror *et al.* (1989), Richards and Davies (1977), Talbot (1975), Fraser (1936), Kirby (1914), Distant (1902), and Bingham (1897). Most of the coleopterans and dipterans were identified to the lowest taxonomic level using a standard identification key or manual from Bug Guide (2022). Most of the bee species were confirmed as pollinators from the bee's pollinator list given by Hannan (2003). Most of the Butterflies and moths were identified from the photographs provided by Chowdhury and Hossain (2011). Birds were identified by utilizing information and photographs from the books of Khan (2008), Siddiqui *et al.* (2008), Parween and Reza (2017) and a website named eBird (2022). Identification of the genera and species of some insects and non-insects were also done by using the Google lens software on the internet (Version: 1.14.220323016).

Considering the study mainly focused on insect visitation, flowering time in various plants was also documented. The visit of a specific insect species to a specific flower was recorded. By using a digital camera (Canon EOS 750D), majority of the specimens of insect and non-insect pollinators were photographed on the flower while foraging, and some others were photographed after collecting in which the date and time of the collections were recorded.

Status of the Specimens: Status of the specimens were categorized into one of the five categories based on their abundances according to the categorization given by Mahdi *et al.* (2021) and Chowdhury *et al.* (2014) as, VC, Very Common (more than 50 individuals); C, Common (31-50 individuals); FC, Fairly Common (16-30 individuals); R, Rare (6-15 individuals) and VR, Very Rare (1-5 individuals).

Statistical Analyses: Six commonly used biodiversity indices *viz.* Shannon-Wiener Diversity Index, Simpson Diversity Index, Margalef Diversity Index, Menhinick Richness Index, Berger-Parker Dominance Index and Pielou's Evenness Index were employed to assess the diversity of different pollinating animals (Shannon, 1948; Simpson, 1949; Margalef, 1958; Menhinick, 1964; Pielou, 1966; Berger and Parker, 1970). Microsoft Excel 2021 was used to analyze all of the data that was obtained. The relative abundance of the pollinators was calculated using the following formula:

$$\text{Relative Abundance (RA)} = \frac{\textit{Number of individuals of a specific species } (n)}{\textit{Total number of individuals } (N)} \times 100$$

RESULTS AND DISCUSSION

During the present study, various insects and other animals visiting flowers were recorded and mainly divided into two categories: insect and non-insect pollinators (Fig. 2). Species diversity and relative abundances of pollinators, which were observed and collected from flowers of different crop and non-crop plants in the study area have been presented in Tables 1 and 2. In case of insect pollinators, a total of 3007 individuals were observed and collected, in which 93 species were identified under 74 genera of 38 families and seven orders (Table 1). In insect pollinators, the maximum of 32 species (individuals, n= 1074; relative abundance, RA= 32.70 %) were recorded in the order Lepidoptera followed by Hymenoptera 24 species (n= 844; RA= 25.70 %) > Diptera 15 (n= 417; RA= 12.70 %) > Coleoptera 13 (n= 501; RA= 15.26 %) > Orthoptera 5 (n= 61; RA= 1.86 %) > Odonata 3 (n= 99; RA= 3.01 %) > Hemiptera 1 (n= 11; RA= 0.33 %) (Table 1). The most abundant insect family was Apidae with four species (n= 267, RA= 8.12%) and the most dominant species of insect pollinator was *Eurema hecabe* (n= 95, RA= 2.89%) (Table 1).

Table 1. Species diversity and relative abundances of insect pollinators in Puthia, Rajshahi. Relative Abundance (RA) is calculated based on the total number of individuals in Tables 1 and 2. Abbreviation of status was mentioned in Table 3

Order	Family	Species	Individual (n)	RA (%)	Status
Odonata	Libellulidae	*Sympetrum fonscolombii*	35	1.07	C
	Platycnemididae	*Onychargia atrocyana*	20	0.61	FC
	Coenagrionidae	*Ceriagrion coromandelianum*	44	1.34	C
Orthoptera	Acrididae	*Acrida exaltata*	7	0.21	R
		Oxya hyla	18	0.55	FC
		Chorthippus brunneus	20	0.61	FC
	Tetrigidae	*Euparatettix histricus*	12	0.37	R
	Gryllidae	*Gryllus* sp.	4	0.12	VR
Hemiptera	Pentatomidae	*Carpocoris purpureipennis*	11	0.33	R
Lepidoptera	Danaidae	*Danaus genutia*	48	1.46	C
		D. chrysippus	70	2.13	VC
	Papilionidae	*Euploea core*	33	1.00	C
		Papilio polytes	42	1.28	C
		P. demoleus	59	1.80	VC
	Pieridae	*Catopsilia pyranthe*	15	0.46	R
		C. pomona	18	0.55	FC

Order	Family	Species	Individual (n)	RA (%)	Status
		Cepora nerissa	12	0.37	R
		Pieris canidia	40	1.22	C
		Eurema hecabe	95	2.89	VC
		Delias eucharis	8	0.24	R
		Phalantha phalantha	41	1.25	C
		Ariadne merione	5	0.15	VR
		Junonia atlites	60	1.83	VC
	Nymphalidae	*J. almana*	61	1.86	VC
		Euthalia aconthea	28	0.85	FC
		Melanitis phedima	20	0.61	FC
		Hypolimnas bolina	23	0.70	FC
		Tajuria cippus	23	0.70	FC
	Lycaenidae	*Chilades parrhasius*	13	0.40	R
		Neopithecops zalmora	55	1.67	VC
		Hypolycaena erylus	7	0.21	R
		Parnara guttatus	72	2.19	VC
		Pelopidas conjuncta	32	0.97	C
	Hesperiidae	*Borbo cinnara*	29	0.88	FC
		Pompeius verna	8	0.24	R
		Oriens gola	35	1.07	C
	Satyridae	*Elymnias hypermnestra*	39	1.19	C
		Ypthima huebneri	14	0.43	R
	Zygaenidae	*Trypanophora semihyalina*	20	0.61	FC
	Erebidae	*Amata cyssea*	45	1.37	C
	Scythrididae	*Eretmocera impactella*	4	0.12	VR
		Episyrphus balteatus	46	1.40	C
	Syrphidae	*Mesembrius bengalensis*	22	0.67	FC
		Eristalinus quinquestriatus	17	0.52	FC
	Sarcophagidae	*Sarcophaga carnaria*	18	0.55	FC
		S. crassipalpis	4	0.12	VR
	Muscidae	*Musca domestica*	62	1.89	VC
Diptera		*Calliphora vomitoria*	11	0.33	R
	Calliphoridae	*Lucilia silvarum*	33	1.00	C
		L. sericata	51	1.55	VC
		Chrysomya megacephala	37	1.13	C
	Tephritidae	*Bactrocera cucurbitae*	27	0.82	FC
	Culicidae	*Culex pipiens*	31	0.94	C
	Rhiniidae	*Stomorhina lunata*	44	1.34	C

Order	Family	Species	Individual (n)	RA (%)	Status
Hymenoptera	Stratiomyidae	*Oplodontha viridula*	7	0.21	R
		O. rubrithorax	7	0.21	R
	Apidae	*Apis dorsata*	73	2.22	VC
		A. cerana	55	1.67	VC
		A. florea	51	1.55	VC
		A. mellifera	88	2.68	VC
	Megachilidae	*Megachile sculpturalis*	2	0.06	VR
	Xylocopidae	*Xylocopa aestuans*	38	1.16	C
		X. latipes	39	1.19	C
		X. nasalis	9	0.27	R
		X. virginica	53	1.61	VC
		X. violacea	35	1.07	C
	Sphecidae	*Sphex pensylvanicus*	58	1.77	VC
		Chalybion bengalense	52	1.58	VC
		Rhynchium quinquecinctum	12	0.37	R
	Vespidae	*Polistes olivaceus*	54	1.64	VC
		P. stigma	3	0.09	VR
		Delta pyriforme	24	0.73	FC
		Parancistrocerus fulvipes	3	0.09	VR
		Monobia quadridens	2	0.06	VR
	Ichneumonidae	*Megarhyssa* sp.	5	0.15	VR
	Pompilidae	*Pompilus humilis*	2	0.06	VR
	Formicidae	*Camponotus pennsylvanicus*	71	2.16	VC
		C. compressus	52	1.58	VC
		Monomorium minimum	25	0.76	FC
		Brachymyrmex patagonicus	38	1.16	C
Coleoptera	Coccinellidae	*Coccinella septempunctata*	73	2.22	VC
		C. transversalis	60	1.83	VC
		Cheilomenes sexmaculata	51	1.55	VC
	Cantharidae	*Harmonia axyridis*	31	0.94	C
		Rhagonycha fulva	46	1.40	C
		Chauliognathus pensylvanicus	19	0.58	FC
	Chrysomelidae	*Longitarsus* sp.	3	0.09	VR
		Cryptocephalus coryli	55	1.67	VC
		Aulacophora foveicollis	51	1.55	VC
		A. lewisii	58	1.77	VC
		A. indica	49	1.49	C

Order	Family	Species	Individual (n)	RA (%)	Status
	Scarabaeidae	*Glycyphana horsfieldi*	3	0.09	VR
	Carabidae	*Ophionea indica*	2	0.06	VR

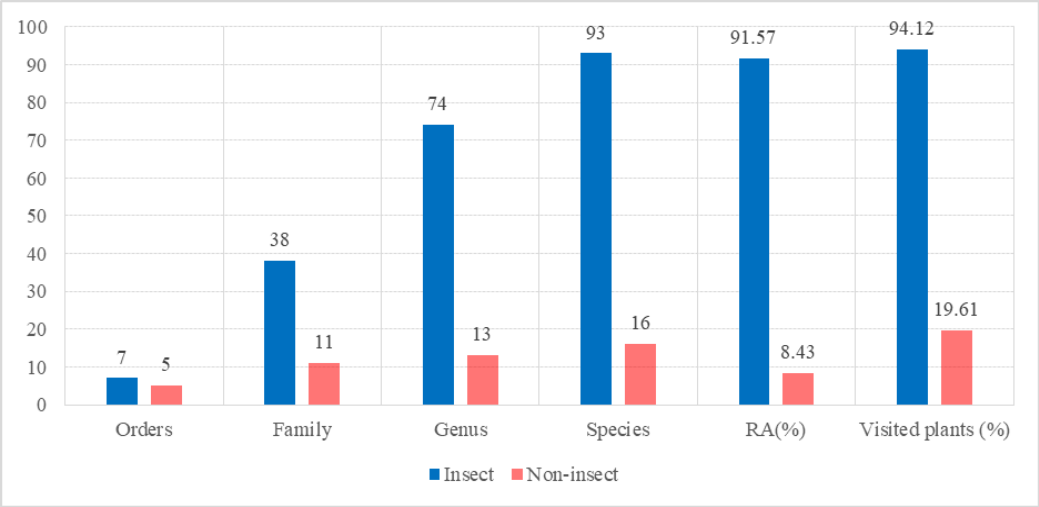

Fig. 2. Comparison between insect and non-insect pollinators in the study area. Here 13.73% plants were common for both insects and non-insects.

In case of non-insect pollinators, a total of 277 individuals were observed, in which 16 species were identified under 13 genera belonging to 11 families of five orders and two classes (Table 2). In non-insect pollinators, the maximum of 11 species (n= 221; RA= 6.73 %) were observed in the order Passeriformes followed by Piciformes 2 (n= 40; RA= 1.22 %) > Psittaciformes 1 (n= 8; RA= 0.24 %) > Rodentia 1 (n= 5; RA= 0.15 %) > Chiroptera 1 (n= 3; RA= 0.09 %). The most abundant non-insect family was Pycnonotidae with two species (n= 44, RA= 1.34%) and the most dominant non-insect pollinator was *Pycnonotus cafer* (n= 37, RA= 1.13%) (Table 2). Birds play a critical role in wildflower pollination all around the world, and birds pollinate flowers with vibrant colours that bloom during the day. In the present study, 14 bird species were found on Sponge gourd, Silk cotton, Papaya, Banana, Mango, Drumstick, Boroi, and Royal poinciana flowers. Also, a Rodent species (*Funambulus palmarum)* and a bat species (*Pteropus* sp.) were seen to be visited on the *B. ceiba* flowers (Table 5, 6).

A total of 3284 individuals of insect and non-insect pollinators were collected and observed on flowers of different crop and non-crop flowering plants under the study area in which 109 species under 49 families, 12 orders and three classes of two phyla were identified (Table 1, 2). The number of identified species and their relative abundances (RA), the chronology of the orders in the ascending way was Lepidoptera (spp.= 32, RA= 32.70%) > Hymenoptera (spp.= 24, RA= 25.70 %) > Diptera (spp.= 15, RA= 12.70 %) > Coleoptera (spp.= 13, RA=

15.26 %) > Passeriformes (spp.= 11, RA= 6.73 %) > Orthoptera (spp.= 5, RA= 1.86 %) > Odonata (spp.= 3, RA= 3.01%) > Piciformes (spp.= 2, RA= 1.22 %) > Hemiptera (sp.= 1, RA= 0.33 %) > Psittaciformes (sp.= 1, RA= 0.24 %) > Rodentia (sp.= 1, RA= 0.15 %) > Chiroptera (sp.= 1, RA= 0.09 %). The most abundant

Table 2. Species diversity and relative abundances of non-insect pollinators in Puthia, Rajshahi. Relative Abundance (RA) is calculated based on the total number of individuals in Tables 1 and 2. Abbreviation of status was mentioned in Table 3

Class	Order	Family	Species	Individual (n)	RA (%)	Status
Aves	Passeriformes	Nectariniidae	*Cinnyris asiaticus*	32	0.97	C
		Pycnonotidae	*Pycnonotus cafer*	37	1.13	C
			P. jocosus	7	0.21	R
		Sturnidae	*Acridotheres fuscus*	6	0.18	R
			A. tristis	18	0.55	FC
			Sturnia malabarica	12	0.37	R
		Dicruridae	*Dicrurus hottentottus*	35	1.07	C
			D. paradiseus	2	0.06	VR
		Corvidae	*Corvus splendens*	31	0.94	C
			Dendrocitta vagabunda	10	0.30	R
		Oriolidae	*Oriolus xanthornus*	31	0.94	C
	Psittaciformes	Psittaculidae	*Psittacula krameri*	8	0.24	R
	Piciformes	Megalaimidae	*Megalaima asiatica*	8	0.24	R
		Picidae	*Dinopium benghalense*	32	0.97	C
Mammals	Rodentia	Sciuridae	*Funambulus palmarum*	5	0.15	VR
	Chiroptera	Pteropodidae	*Pteropus* sp.	3	0.09	VR

family was Apidae (n= 267, RA= 8.12%) and the most dominant species was *Eurema hecabe* (n= 95, RA= 2.89%) in the study area (Table 1, 2). Further, the status of pollinators, based on the number of individuals, 25 species were very common, 29 species were common, 18 species were fairly common, 21 species were rare and 16 species were very rare visitors (Table 3). According to the Table 4, the Shannon (H') and Simpson (1-D) diversity indices were 4.41 and 0.99, respectively. The Berger-Parker dominance (d) and Pielou's evenness index (J') were 0.03 and 0.94, respectively, while the Margalef (D_{Mg}) and Menhinick (D_{Mn}) species richness indices were 13.34 and 1.90, respectively. In this study, 32 crop plants have been recorded that were visited by 65 pollinator species (49 insects and 16 non insects) during their flowering periods in the study area and 30 of them were exclusive means they were never seen to be visited on non-crop

flowering plants (Table 5). Among these crop plants, the flowers of Sponge gourd (*Luffa acutangula*) were visited by the maximum number of pollinator species (12) followed by 11 pollinator species visited in each of Silk cotton (*Bombax ceiba*) and Cucumber (*Cucumis sativus*) flowers

Table 3. Status of the pollinators in the study area. Status: VC, Very Common (> 50 individuals); C, Common (31–50 individuals); FC, Fairly Common (16–30 individuals); R, Rare (6–15 individuals) and VR, Very Rare (1-5 individuals)

Order	Status by number (N=109)					Total No. of species
	Very common	Common	Fairly common	Rare	Very rare	
Odonata	-	2	1	-	-	3
Orthoptera	-	-	2	2	1	5
Hemiptera	-	-	-	1	-	1
Coleoptera	6	3	1	1	3	13
Diptera	2	5	4	3	1	15
Hymenoptera	10	4	2	2	6	24
Lepidoptera	7	9	7	7	2	32
Passeriformes	-	5	1	4	1	11
Psittaciformes	-	-	-	1	-	1
Piciformes	-	1	-	1	-	2
Rodentia	-	-	-	-	1	1
Chiroptera	-	-	-	-	1	1
Total No. of species	**25**	**29**	**18**	**21**	**16**	**109**

Table 4. Values of different diversity indices of insect and non-insect pollinators together in the study area

Name of indices	Value
Shannon diversity index (H')	4.41
Simpson diversity index (1-D)	0.99
Margalef diversity index (D_{Mg})	13.34
Menhinick richness index (D_{Mn})	1.90
Berger-Parker dominance index (d)	0.03
Pielou's evenness index (J')	0.94

(Table 5). Black carpenter ant (*Camponotus pennsylvanicus*) has visited at the maximum number of 17 crop plants followed by *A. cerana* visited 13 and *A. mellifera* visited 12 crop plants (Table 5). The month from January to April was recorded as the most visited period for pollinators in crop plants; that number was 52 species (38 insects and 14 non-insects) (Table 5). May to August was the second most visited period, total of 21 species (18 insects and 3 non-insects) visited several crop plants in this period. The period of September to December was found to be visited by the lowest number of pollinators in crop plants. A total of 20 species (19 insects and 1 non-insect) visited different crop plants during this period (Table 5).

Table 5. List of crop plants that received different pollinator species in the study area

Host Plant				
English Name	**Scientific Name**	**Family**	**Flowering Period**	**Visited Pollinators**
Rice	*Oryza sativa*	Poaceae	October to November	*A. exaltata*, *O. hyla*, *C. brunneus*, *E. hecabe*, *A. cerana*, *A. dorsata*, *A. mellifera*, *D. chrysippus*, & *C. septempunctata*
Maize	*Zea mays*	Poaceae	February to March	*M. sculpturalis*, *A. cerana*, *A. mellifera*, *A. dorsata*, *A. florea*, *M. domestica*, *C. pipiens*, & *C. pennsylvanicus*
Brinjal	*Solanum melongena*	Solanaceae	November to December	*S. lunata*, *A. foveicollis*, *A. lewisii*, *X. aestuans* & *X. latipes*
Bottle Gourd	*Lageneria siceraria*	Cucurbitaceae	January to February	*A. dorsata*, *A. mellifera*, *A. cerana*, *B. cucurbitae*, *C. asiaticus*, & *C. pennsylvanicus*
Pumpkin	*Cucurbita moschata*	Cucurbitaceae	November to December	*E. hecabe*, *C. septempunctata*, *C. transversalis*, & *C. pennsylvanicus*
Common Beans	*Phaseolus vulgaris*	Fabaceae	November to December	*C. pennsylvanicus*, & *C. asiaticus*
Mung Beans	*Vigna radiata*	Fabaceae	April to May	*C. pennsylvanicus*, & *B. patagonicus*
Black Gram	*Vigna mungo*	Fabaceae	October to November	*A. exaltata*, *O. hyla*, *C. brunneus*, *X. violacea*, *E. hecabe*, *P. verna*, & *C. pennsylvanicus*
Mustard	*Brassica campestris*	Brassicaceae	January to February	*E. hecabe*, *D. chrysippus*, *X. violacea*, *A. cerana*, *A. mellifera*, *A. dorsata*, *A. florea*, *P. olivaceus*, *C. pennsylvanicus* & *S. lunata*
Wheat	*Triticum aestivum*	Poaceae	January to February	*E. hecabe*, *D. chrysippus*, *X. violacea*, *A. cerana*, *A. dorsata*, & *A. mellifera*
Lentil	*Lens culinaris*	Fabaceae	January to February	*M. minimum*, & *C. septempunctata*
Grass Pea	*Lathyrus sativus*	Fabaceae	February to March	*E. histricus*, *Gryllus* sp., *E. hecabe*, *N. zalmora*, & *C. pennsylvanicus*
Field Pea	*Pisum sativum*	Fabaceae	February to March	*E. hecabe*, *N. zalmora*, & *C. pennsylvanicus*
Onion	*Allium cepa*	Amaryllidaceae	February to March	*A. dorsata*, *A. mellifera*, *E. balteatus*, *M. bengalensis*, *S.*

English Name	Host Plant		Flowering Period	Visited Pollinators
	Scientific Name	Family		
Litchi	*Litchi chinensis*	Sapindaceae	January to March	*carnaria* & *S. crassipalpis* *P. cafer, Megarhyssa* sp., *X. aestuans*, *X. latipes*, & *O. atrocyana*
Mango	*Mangifera indica*	Anacardiaceae	January to March	*D. hottentottus*, *C. asiaticus*, *X. aestuans*, *X. latipes*, *C. pennsylvanicus*, *L. silvarum*, & *R. fulva*
Ber/Boroi	*Ziziphus mauritiana*	Rhamnaceae	September to November	*C. asiaticus*, *M. minimum,* & *C. pennsylvanicus*
Pomegranate	*Punica granatum*	Lythraceae	March to May	*M. domestica*, *C. pennsylvanicus*, & *M. minimum*
Drumstick	*Moringa oleifera*	Moringaceae	March to April	*C. pennsylvanicus*, *C. asiaticus*, & *P. cafer*
Okra	*Abelmoschus esculentus*	Malvaceae	February to March	*A. cerana*, *A. florea*, & *E. hecabe*
Sesame	*Sesamum indicum*	Pedaliaceae	May to June	*A. dorsata*, *A. mellifera*, *A. cerana*, *A. florea*, *P. olivaceus*, *C. vomitoria*, *C. compressus*, *B. cinnara*, & *C. purpureipennis*
Cucumber	*Cucumis sativus*	Cucurbitaceae	January to February	*H. axyridis*, *C. sexmaculata*, *C. septempunctata*, *C. transversalis*, *C. pensylvanicus*, *A. foveicollis*, *A. lewisii*, *A. indica*, *O. indica*, *M. minimum*, & *B. patagonicus*
Sponge Gourd	*Luffa acutangula*	Cucurbitaceae	May to June	*A. dorsata*, *A. mellifera*, *A. florea*, *A. cerana*, *P. guttatus*, *P. conjuncta*, *C. compressus*, *E. quinquestriatus*, *C. pennsylvanicus*, *A. lewisii*, *R. fulva*, & *P. olivaceus*
Wax Gourd	*Benincasa hispida*	Cucurbitaceae	May to June	*C. transversalis*, *B. patagonicus*, & *C. asiaticus*
Coriander	*Coriandrum sativum*	Apiaceae	February to March	*A. florea*, *A. cerana*, *A. mellifera*, *A. dorsata*, *E. balteatus*, & *C. septempunctata*
Banana	*Musa paradisiaca*	Musaceae	August to September	*C. pennsylvanicus*, *D. vagabunda*, & *D. benghalense.*
Papaya	*Carica papaya*	Caricaceae	February to April	*D. paradiseus*, *M. asiatica*, & *P. cafer.*
Tomato	*Solanum lycopersicum*	Solanaceae	March to April	*E. hecabe*, *A. cerana*, *A. mellifera*, & *M. domestica*
Lemon	*Citrus limon*	Rutaceae	January to March	*A. mellifera*, *A. cerana*, *A. florea*, *M. domestica*, *C. pipiens*, *C. pennsylvanicus*, & *E. balteatus*
Pomelo	*Citrus maxima*	Rutaceae	January to March	*A. mellifera*, A. *cerana*, *A. florea*, *M. domestica*, *C. pipiens*, *C. pennsylvanicus*, & *E. balteatus*
Silk Cotton	*Bombax ceiba*	Malvaceae	February to March	*P. cafer*, *P. jocosus*, *A. fuscus*, *S. malabarica*, *C. splendens*, *O. xanthornus*, *P. krameria*, *A. tristis*, *M. asiatica*, *F. palmarum* & *Pteropus* sp.
Sunflower	*Helianthus annuus*	Asteraceae	February to March	*A. mellifera*, *A. dorsata*, *A. cerana*, & *M. domestica*

In the present study, 19 non-crop flowering plants have been recorded also, that were visited by 79 pollinator species (76 insects and 3 non insects) during their flowering periods in the study area and 44 of them were exclusive means they were never seen to be visited on crop plants (Table 6). Among these, the flowers of Orangeberry (*Glycosmis pentaphylla*) were visited by the maximum number of pollinator species (55) followed by 6 pollinator species visited on Carrot grass (*Parthenium hysterophorus*) flowers. Also, 5 pollinator species were found to be visited on each of Crape jasmine, Indian heliotrope and Thistle flowers (Table 6). The Black carpenter ant (*Camponotus pennsylvanicus*) have visited at the maximum number of 7 non-crop plants followed by *A. mellifera* and *P. guttatus* visited 4 non-crop plants each (Table 6). The month from September to December was recorded the most visited period for pollinators in non-crop plants; that number was 69 insect species (Table 6). The month from January to April was the second most visited period, total of 13 insect species visited several non-crop plants in this period. The period of May to August was found to be visited by the lowest number of pollinator species in non-crop plants. Only 3 bird species have found during this period that were visited Royal poinciana flowers (Table 6).

Table 6. List of non-crop flowering plants that received different pollinator species in the study area

Host Plant				Visited Pollinators
English Name	**Scientific Name**	**Family**	**Flowering Period**	
Marigold	*Tagetes patula*	Asteraceae	November to January	*E. quinquestriatus*, *C. pipiens and C. pennsylvanicus*
Common Jasmine	*Jasminum sambac*	Oleaceae	November to December	*C. pennsylvanicus*
Crape Jasmine	*Tabernaemontana divaricata*	Apocynaceae	November to December	*P. guttatus, P. conjuncta*, *L. sericata, C. pennsylvanicus, & M. minimum*
Orangeberry	*Glycosmis pentaphylla*	Rutaceae	November to December	*C. coromandelianum*, *A. dorsata*, *A. cerana*, *A. florea*, *A. mellifera*, *M. sculpturalis*, *X. aestuans*, *X. latipes*, *X. nasalis*, *X. virginica*, *X. violacea, S. pensylvanicus*, *C. bengalense*, *R. quinquecinctum*,

Host Plant				Visited Pollinators
English Name	**Scientific Name**	**Family**	**Flowering Period**	
Thistle	*Cirsium vulgare*	Asteraceae	February to March	*P. stigma*, *D. pyriforme*, *P. fulvipes*, *M. quadridens*, *P. humilis*, *C. pennsylvanicus*, *L. silvarum*, *C. megacephala*, *D. genutia*, *D. chrysippus*, *E. core*, *P. polytes*, *C. pyranthe*, *C. pomona*, *C. nerissa*, *P. canidia*, *E. hecabe*, *D. eucharis*, *P. phalantha*, *A. merione*, *J. atlites*, *J. almana*, *B. cinnara*, *E. aconthea*, *M. phedima*, *H. bolina*, *P. demoleus*, *T. cippus*, *C. parrhasius*, *N. zalmora*, *H. erylus*, *P. guttatus*, *P. conjuncta*, *A. cyssea*, *P. verna*, *O. gola*, *E. hypermnestra*, *Y. huebneri*, *T. semihyalina*, *C. coryli*, & *G. horsfieldi* *A. dorsata*, *A. mellifera*, *R. fulva*, *C. septempunctata*, & *Longitarsus* sp.
Crown of Thorn	*Euphorbia milii*	Euphorbiaceae	November to December	*M. minimum P. olivaceus*, & *O. rubrithorax*
Yellow Oleander	*Cascabela thevetia*	Apocynaceae	November to December	*P. guttatus*, & *P. conjuncta* *A. mellifera*, *A. cerana*, *A. florea*, & *C. pennsylvanicus*
Jungle Flame	*Ixora coccinea*	Rubiaceae	November to December	
Goosefoot	*Chenopodium album*	Amaranthaceae	January to February	*S. fonscolombii*
Mexican Mint	*Coleus amboinicus*	Lamiaceae	March to April	*P. polytes*, *P. demoleus*, & *C. nerissa*

Host Plant				Visited Pollinators
English Name	**Scientific Name**	**Family**	**Flowering Period**	
Bhat	*Clerodendrum viscosum*	Lamiaceae	March to April	*P. polytes*, *P. demoleus*, & *C. nerissa*
Pea Pumpkin	*Cucumis maderaspatana*	Cucurbitaceae	November to December	*P. guttatus*, & C. *pennsylvanicus*
Carrot grass	*Parthenium hysterophorus*	Asteraceae	November to December	*M. domestica*, *C. vomitoria*, *C. pipiens*, *S. lunata*, *O. viridula*, & *O. rubrithorax*
Cockscomb	*Celosia argentea*	Amaranthaceae	November to December	*L. sericata*, *C. parrhasius*, & *D. pyriforme*
Marsh Para Cress	*Acmella uliginosa*	Asteraceae	November to December	*E. hecabe*, & *E. impactella*
Indian Heliotrope	*Heliotropium indicum*	Boraginaceae	March to April	*C. septempunctata*, *H. axyridis*, *C. sexmaculata*, *C. transversalis*, & *C. pensylvanicus*
Candle Bush	*Senna alata*	Fabaceae	November to December	*C. pennsylvanicus*, & *C. compressus*
Red Coleus	*Coleus scutellarioides*	Lamiaceae	November to December	*A. dorsata*, & *A. mellifera*
Royal Poinciana	*Delonix regia*	Fabaceae	April to June	*A. tristis*, *P. cafer*, & *C. asiaticus*

Overall, 51 crop and non-crop flowering plants were recorded in this study that were visited by 109 pollinators (93 insects and 16 non insects) during their respective flowering periods in the study area (Table 5, 6). Among the recorded plants, 80.39% were only visited by insects, 5.88% were only visited by non-insects (birds and mammals) and 13.73% were common visitors (Fig. 2). Among the recorded pollinators, 30 species were exclusively visited crop plants, 44 species were exclusively visited non-crop flowering plants and 35 species were common in both crop and non-crop flowering plants. The Black carpenter ant (*C. pennsylvanicus*) visited the most number (24) of plants species followed by *Apis mellifera* visited 16 and *Apis cerana* visited 15 plant species. The month from September to December was recorded as most visited period for pollinators; that number was 77 species (76 insects and 1 non-insects). The period of January to April was the second most visited period, total of 57 pollinator species (43 insects and 14 non-insects) visited different plants (Table 5, 6). The period of May to August was found to be visited by the lowest number of pollinators in crop and non-crop plants. Total 23 species (18 insects and 5 non insects) have been found visited different flowers during this period (Table 5, 6).

Pollinators, both insects and other animals, play a crucial role in the reproduction of many plant species. The mutualistic relationship between plants and pollinators is not only ecologically significant but also economically valuable, as it affects the production of fruits, vegetables, and other crops. Various insect groups play an important role in pollination of different agricultural, horticultural and medicinal herbs crops. It belongs to the orders Hymenoptera, Diptera, Coleoptera, Lepidoptera, Thysanoptera, Hemiptera and Neuroptera (Free, 1993; Kearns *et al.*, 1998). The present study revealed 109 animal pollinators under 49 families of 12 orders in 51 different agricultural crops and non-crop flowering plants. It was reported that a total 368 species in 115 families of 7 orders were recorded to serves as pollinators in 43 different agricultural crops and wild flower in Korea (Choi *et al.* 2015). In our study, the relative abundance of insect and non-insect pollinators was 91.57% and 8.43%, respectively while 94.12% of plants were pollinated by insects, 19.61% were pollinated by vertebrates (birds, bats and rodents) and 13.73% were pollinated by both. A similar type of report was published that about 90% of angiosperm plants are pollinated by insects like bees, beetles, moths and flies (Hoshiba and Sakai, 2008). Furthermore, six types of diversity indices were used in our study, and the values are supported by several previous studies of Mahdi *et al.* (2018, 2020a, 2020b, 2021).

In the present study, we have found the most diverse insect pollinators were the species of Lepidoptera (32 species, 1074 individuals), followed by Hymenoptera (24 species, 844 individuals). The dominant insect pollinator was common grass yellow butterfly (*Eurema hecabe*, 95 individuals) followed by Honeybee (*Apis mellifera*, 88 individuals). Choi *et al.* (2015) found the most diverse insect pollinators of agricultural crops and wild flowering plants were the species of Hymenoptera (110 species, 373 individuals), followed by Diptera (104 species, 219 individuals) and the most dominant insect pollinator was *Apis mellifera* (Hymenoptera, 34 individuals) followed by *Eristalis cerealis* (Diptera, 26 individuals). However, they didn't find any species from the order Orthoptera, Odonata and Hemiptera.

Lepidopterans are vital pollinators of flowering plants in wild ecosystems and managed systems such as parks and yards (Ostiguy 2011). The present study also showed the Lepidoptera as the most dominant order to visit flowering plants. Although Lepidopterans were the dominant pollinators in our study, Hymenopterans were the main pollinators in some studies, especially bees, who spend most of their life collecting pollen (Aizen and Harder, 2009). Previously reported that Bangladesh is the home of 70 different species of pollinating bees and social bee species *Apis dorsata*, *A. cerana*, *A. florea*, *A. mellifera*, *Trigona fuscobaltiata*, *Bombus eximius*, and *B. montivagus* play an essential role in the ecosystem as natural pollinators of different plant species (Amin *et al.* 2014;

Bhuiya and Miah 1990). *Apis dorsata*, *A. cerana*, *A. florea*, and *A. mellifera* were also discovered to be natural pollinators of numerous plant species in the present study.

Beetles (Coleoptera) are the largest insect group, and they are involved in pollinating a wide range of plant species with numerous reproductive traits, pollinating 88% of the 240,000 flowering plants (Endress, 1994). In Australia, 28 coleopteran families and 44 dipteran families include flower-visiting insects (Armstrong, 1979). In the present study, only 8 families of Diptera and 5 families of Coleoptera were identified. Flies (Diptera) are considered the second most dominant insect order for pollination (Larson *et al.*, 2001). In our study, flies were the third most diverse flower-visiting insect group.

Hymenopterans were spotted on the blooms of *Luffa cylindrica* by Agarwal and Rastogi (2008). These results provide substantial support for the current study. Earlier, *Xylocopa* bees were recognized by Njorage *et al.* (2004) as pollinators of cucurbit crops. However, the present findings showed that *Cucumis sativus* flower was visited exclusively by Coleopterans and ants. While Thapa (2006) noted lady beetles (*Coccinella*) as cucumber, pumpkin, and brinjal pollinators, corroborating the present findings. Mangos are mostly pollinated by insects from the Diptera, Hymenoptera, Coleoptera, and Hemiptera order (Chauhan *et al.* 2020), which is consistent with the findings of the current study.

In addition to insects, two other types of nectar-feeding (nectarivorous) vertebrates, namely birds and bats, also contribute significantly to pollination. For instance, just 3-11% of species in a range of lowland tropical forests are pollinated by birds and bats (Devy and Davidar, 2003). In our study, it was found that 19.61% plants were pollinated by the help of birds and bats. According to Sekercioglu (2006), bird pollination is more prevalent than bat pollination, which also supports the present study. Diller *et al.* (2019) counted 242 opportunistic floral visitors and 77 specialist flower visitors. During their survey, the most observed birds were Weavers, Cape glossy starling, dark-capped bulbul, fork-tailed drongo and white-bellied sunbird. This corroborates the current study because sunbirds, bulbuls, starlings, drongos, and other bird species were also seen to be visited many flowers in the study area.

CONCLUSION

Pollinator diversity and plant-pollinator interactions are essential for the functioning of terrestrial ecosystems. The involvement of insects in general, and bees in particular, in crop plant pollination, is critical for increased crop productivity. During the current inquiry, the predominant visitors in the study area were Honeybees (*Apis dorsata* and *A. mellifera*), Plain tiger butterfly (*Danaus chrysippus*), Common grass yellow butterfly (*Eurema hecabe*), Rice

skipper (*Parnara guttatus*), Ladybird beetle (*Coccinella septempunctata*), and Black carpenter ant (*Camponotus pennsylvanicus*). Those were very abundant (more than 70 individuals) and visited a large number of flowers in the study area during the study period. Insect groups that contributed significantly to the pollination were Flies (Diptera), beetles (Coleoptera), bugs (Hemiptera), wasps (Hymenoptera), and even grasshoppers (Orthoptera). Ants (Hymenoptera) spent significantly longer duration on flowers compared to other insects. Most butterflies and moths (Lepidoptera) species visited flowers for nectar, but their contribution to pollination services was unknown. Many butterfly species flew large distances between flowers and might transport pollen for extended periods of time. Along with insects, nectar-feeding birds and mammals were also observed on different flowers under the study area. However, in our study area, we have found that non-crop plants were visited by large number of pollinators with high taxonomic diversity, which suggest the significant roles of non-crop flowering plants for conservation of pollinators. Further studies are needed for detailed research on pollinator diversity and mutual interactions between plants and pollinators in broad ecosystems.

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