ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 46(3): 297-306, September 2021

IMPACT OF FORAGING INSECT POLLINATORS ON CHILI PRODUCTION

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Abstract

The abundance, foraging behavior, and diurnal and seasonal dynamics of the pollinator insects in chili ecosystem, and the impact of the pollinator insects on chili production was studied at the Bangabandhu Sheikh Mujibur Rahman Agricultural University, (BSMRAU) Gazipur, Bangladesh using the chili variety BARI Morich 2. The crop was cultivated in natural, supplemented insect and self-pollination conditions. The lime butterfly, honey bee, carpenter bee and sweat bee were found in the chili ecosystem. Honey bee depicted significantly the highest abundance and visitation frequency and carpenter bee was found as the most rapid forager. The diurnal and seasonal abundance of the pollinator insects was fluctuated and the peak abundance was found at 11.00 hour of the day. Abundance of lime butterfly, honey bee and carpenter bee revealed negative relationship with maximum and minimum temperatures, and positive relationship with relative humidity and rainfall. Abundance of sweat bee was positively correlated with maximum and minimum temperatures and rainfall, and negatively correlated with relative humidity. The chili plants exerted vulnerable response to insect pollination producing significantly the higher number of fruits per plant, fruit length, diameter and weight, number of seed per fruit, seed weight and yield.

Keywords: Abundance, behavior, *Capsicum frutescens*, insect pollinators, yield.

Introduction

Chili (*Capsicum* spp.*)* belongs to the family Solanaceae is nutritionally rich in vitamin A, B and C. Chili fruits are pungent because of the constituent of capsaicin, however many varieties are non-pungent which are used as vegetables (Kim *et al*., 2002). Chili was originated from South and Central America and it was first cultivated in Peru where it harbors the greatest diversity of cultivated chili in the world (Meckelmann *et al.*, 2013). Five species of chili especially *C. annuum*, *C. baccatum*, *C. chinense*, *C. frutescens*, and *C. pubescens* have been domesticated and cultivated all over the world.

Chili flowers are self-pollinating and chasmogamous those carry out pollination at the time of the opening of petals. Various pollinating insect species forage in the chili ecosystem and there is substantial possibility of cross pollination by insects of the chasmogamous flowers of chili. Honey bees and other bees visit chili flowers on warm bright days or during dry periods (Vishwakarma, 2018). Insect

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pollinators on chili flowers can improve the quality of fruits, which ultimately affect the yield of chili (Aminatun *et al*., 2019).

Pollinator insects increase fertilization rate in flowering plants by transferring pollen from anther to stigma within a flower or between flowers of the same plant or different plants of the same species. Aminatun *et al.* (2019) reported that nine species of pollinator insects visited the flowers of chili plants with a view to feeding, pollen collection, and warmth.

Insect pollination increased viability of seed, formation of more nutritious fruits, increased seed yield and fruit set (Pudasaini *et al*., 2014; Nancy *et al*., 2019). Foraging behavior, frequency of visitation and pollination efficiency vary among the insect species as they respond to the varying flowering plants, time of the day and season of the year (Amin *et al*., 2015; Amin *et al*., 2019a).

Climate change and intensification of agriculture created alarming circumstances against insect pollinators and their pollination services (Kremen *et al*., 2002; Klein *et al*., 2007). Crop pollination and global food production is at the risk due to declining of many pollinator species (Gallai *et al*., 2009). Now-a-days, different pollinator insects specially honeybees and bumblebees are being commercially reared for pollination of vegetable and fruit crops, and investigations are done to find out the pollination efficiency and impact of the native pollinator insects on various crop plants. Considering the above mentioned points, the study was undertaken to find out the insect pollinator species and their abundance and foraging behavior in chili ecosystem, and their impact on yield and seed quality of chili.

Materials and Methods

The study was conducted from January to June 2019 in the field and laboratory of the Department of Entomology, Bangabandhu Sheikh Mujibur Rahman Agricultural University, (BSMRAU) Gazipur (25°25’ N and 89°5’ E), Bangladesh. Climate of the location is subtropical with mean annual rainfall of 2376 mm, relative humidity of 65.8%, and temperature of 24.4°C (Amin *et al*., 2018). Out of two experiments, one experiment was conducted in 25 sq.m. large plots with three replications to find out the insect pollinator species, their abundance and foraging behavior in chili ecosystem. The other experiment was conducted with three treatments in randomized complete block design and five replications to estimate impact of insects on yield and seed quality of chili. The seeds of chili (*Capsicum frutescens)* variety BARI Morich 2 were collected from the Spices Research Center of Bangladesh Agricultural Research Institute, Bogura. The seedlings were raised in polythene bags and forty days old seedlings were transplanted in the experimental plots on February 25, 2019. The chili plants were cultivated in 5m × 5m plots with three replications to observe the abundance and foraging behavior of the pollinator insects. In this plot, seedlings were transplanted in 10 rows and each row contained 10 plants apart from 50 cm. To investigate the impact of pollinators on fruit set, chili plants were also cultivated in another 15 plots. The size of these plots was 1.5m × 2.5m and the seedlings were transplanted in rows apart from 50 cm. Each of these plots contained 3 rows and each row had five plants. Manures (cow dung 5 $t.ha^{-1}$ and poultry manure 2 $t.ha^{-1}$) and fertilizers (NPKS @ 32, 16, 25 and 3 $kg.ha^{1}$) were applied according to the Fertilizer Recommendation Guide (FRG, 2018). Irrigation and weeding were done as and when needed.

The experimental 15 plots (1.5m × 2.5m) were arranged into three treatments following randomized complete block design with five replications. The treatments were (i) open plot (natural pollination), (ii) enclosed plot (covered with white mosquito net) having ten supplemented insect pollinators i.e. lime butter fly (2), honey bee (3), carpenter bee (3), and sweat bee (2) per week, and (iii) self-pollination (covered with white mosquito net).

Abundance and foraging behavior of the pollinators

The abundance and foraging behavior of the pollinator insects was observed throughout the flowering period. Free-living insects were collected from each of the 5m × 5m experimental plot using a 30 cm diameter sweep net having 1.5 mm mesh, and attached with a 1.5 m long handle. Every week sweeping was done at 07.00, 09.00, 11.00, 01.00 and 03.00 h of the day, and each sample consisted of 30 sweeps. The collected insects were brought to the Entomology Laboratory of BSMRAU and the pollinator insects were separated. The abundance of the pollinator insects, their diurnal dynamics, seasonal incidence and visitation frequency were calculated. *Frequency of the pollinator insects was calculated using the following formula-* $F\ (\%) = \Sigma \frac{nt}{Nt} \times 100$, where, F = Percentage of frequency, nt = Number of individuals belong to a visiting insect species, Nt = Total number of insect species included in the census.

Landing duration of the pollinator insects on chili flowers was measured manually using a stop watch. Arrival and departure times of the visiting-insects on the flowers were recorded and landing duration was calculated. Observations on landing were done in between 10:00 to 11:30 h of the day and data were recorded 50 times for each species.

Effect of pollinators on chili fruit and yield

The impact of insect pollinators on fruit set and number of fruits per plant under the three pollination conditions was evaluated. For this purpose, 2 plants from every plot of each category of pollination condition were randomly selected at the first harvest of fruit (45 days after transplanting) and number of fruits per plant was counted. Five ripe fruits from each of the plot of each pollination condition were randomly selected and their individual lengths and widths were measured using slide-calipers, and the weights were taken using a digital balance (AG204, Mettler Toledo, Switzerland). After that the fruits were sliced with a knife and the number of seeds of each fruit was counted. At every harvest, the plucked fruits of each pollination condition were kept separately and their weights were measured. The fruit yield of each plot was converted into kg/ha. Thousand seed weight of all plots of each pollination condition was taken from sun dried fruits using a digital balance.

Economic value of pollination and crop vulnerability ratio

The economic value of the pollination service was estimated by the contribution of pollinators to the market value of chili production intended for human consumption, and the value was calculated using the formula developed by Gallai *et al.* (2009). The formula for Insect Pollination Economic Value (IPEV) was IPEV $=\sum(P \times Q \times D)$, where, IPEV = Insect Pollination Economic Value, P = Price per unit, Q = Quantity produced due to insect pollination, D = Pollination dependency ratio. The dependency ratio enables the calculation of the production loss in case of a complete disappearance of pollinators. The dependency ratio for chili is of 0.05 (Klein *et al*., 2007; Gallai *et al*., 2009).

Crop vulnerability ratio provides a measure of the potential relative production loss attributable solely to the lack of insect pollination. Crop vulnerability ratio was computed according to the formula of Gallai *et al.* (2009). The formula for Crop Vulnerability Ratio (CVR) was $CVR = \Sigma \frac{IPEV}{EPV}$, where, CVR= Crop Vulnerability Ratio, IPEV = Insect Pollination Economic Value, EPV = Economic Production Value.

Weather information and data analysis

The meteorological data were obtained from the weather station of BSMRAU located 250 m away from the experimental field. One-way analysis of variance (ANOVA) followed by Tukey honestly significant difference test was used for analyzing the abundance and foraging behavior of the pollinator insects, and their impact on chili production. Correlation coefficient (r) values were calculated for pollinator population with meteorological parameters. All the analyses were performed using IBM SPSS 20.0.

Results and Discussion

Four species of insects namely lime butterfly (*Papilio demoleus)*, honey bee (*Apis florea)*, carpenter bee (*Xylocopa violacea)* and sweat bee *(Halictus* sp.) were found in the chili ecosystem (Table 1). Abundance, landing duration and visitation frequency rate of the pollinator insects varied from 2.5±0.2 to 3.5±0.3/30 sweeps, 17.7±1.3 to 25.1±1.5 second, and 21.5±1.9 to 29.8±1.8%, respectively, and the results differed significantly among different species of pollinators. Honey bee showed the highest abundance and visitation frequency rate and the lime butterfly revealed the longest landing duration. Sweat bee and carpenter bee depicted the lowest abundance and landing duration, respectively. Lime butterfly and sweat bee exerted statistically similar and the lowest visitation frequency rate.

Tables 1. Abundance and foraging activity of recorded pollinator insect species in chili ecosystem

Observed pollinator insects	Abundance/ 30 sweeps	Landing duration (Seconds)	Visitation frequency rate (%)
Lime butterfly (*Papilio demoleus)*	2.7±0.1 ab	25.1±1.5a	23.2±0.9b
Honey bee (*Apis florea)*	3.5±0.3a	21.2±1.6ab	29.8±1.8a
Carpenter bees (*Xylocopa violacea)*	2.9±0.2ab	17.7±1.3b	25.5±1.1ab
Sweat bee *(Halictus* sp.*)*	2.5±0.2b	23.1±2.1ab	21.5±1.9b

Abundance, visitation frequency and landing duration of the pollinator insects vary with their behavioral characteristics, growth, survival and reproduction strategies, nesting sites, flowering plant species and geographic locations (Mandal *et al*., 2018).

Diurnal dynamics of the pollinator insects in chili ecosystem showed that the abundances of the insects were increasing from 07.00 hour of the day and reached to the peak at 11.00 hour and then declined (Figure 1). Abundance of honey bee was maximum all the daylong followed by carpenter bee, lime butterfly and sweat bee. In the peak foraging hour, the abundances of honey bee and sweat bee were 6.2 and 5.0 individuals/30 sweeps, respectively. This finding shows agreement with the report of Amin *et al.* (2015) who observed peak foraging activity of the pollinators at 11.0 h of the day. Ahmad and Aslam (2002) reported the peak foraging of pollinator insects on carrot at 8.0 - 9.0 h of the day whereas Kumar and Jaiswal (2012) found the increasing trend of pollinators on coriander from 09.00 to 13.00 h and thereafter declined.

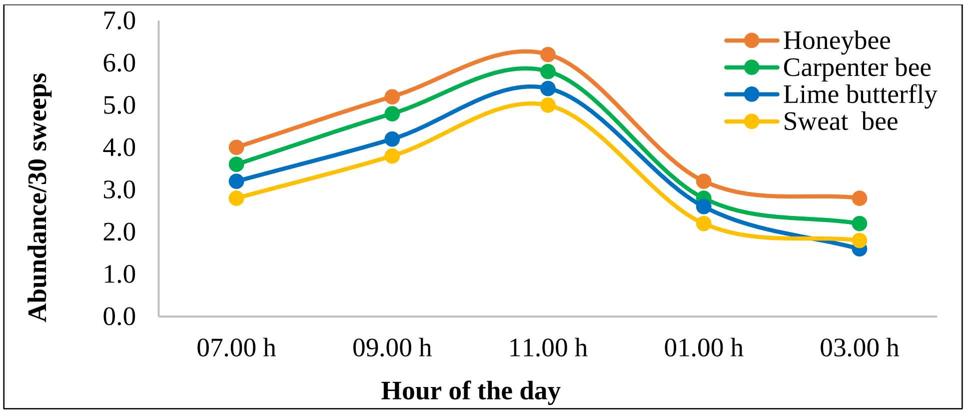

Fig. 1. Diurnal dynamics (sedentary nature) of the insect pollinators in chili ecosystem.

The pollinator insects showed fluctuation in their abundances in the chili ecosystem and they foraged from 1st week of April to the 1st week of May, which coincided with blooming of flower (Figure 2). Honey bee exhibited higher abundance from beginning to end of the blooming season. The peak abundance of carpenter bee (3.7 individuals/30 sweeps) was found in the second week of April when the maximum and minimum temperatures, relative humidity and rainfall were 26°C, 19°C, 91% and 48.7 mm, respectively (Table 2). Lime butterfly and honey bee showed the highest abundance in the third week of April when the maximum and minimum temperatures, relative humidity and rainfall were 34°C, 23°C, 85% and 1.62 mm, respectively.

Table 2. Weather information at Gazipur in Bangladesh from April to May 2019

Observation day	Weather parameters			
	Max. Temperature (˚C)	Min. Temperature (˚C)	Relative humidity (%)	Rainfall (mm)
03 April	31.0	19.0	91	20.13
10 April	26.0	19.0	91	48.7
17 April	34.0	23.0	85	1.62
24 April	35.0	23.5	85	0.0
01 May	36.0	28.0	78	0.0

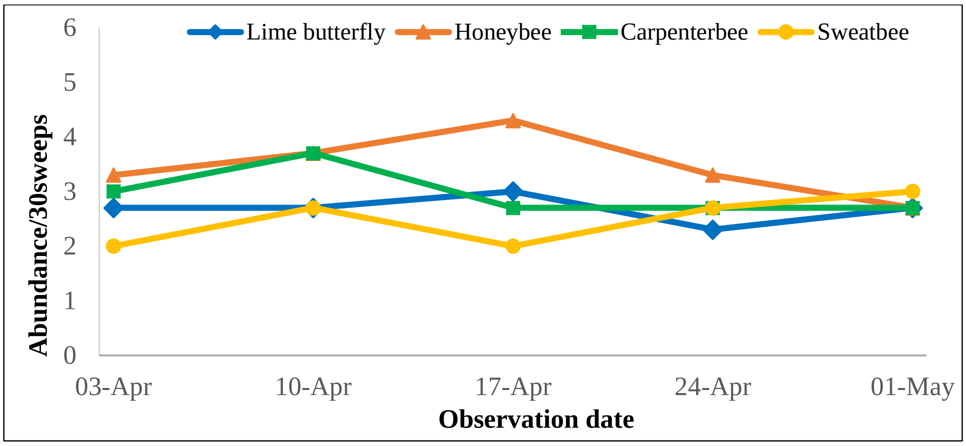

Fig. 2. Seasonal (weekly) dynamics of the pollinator insects in chili ecosystem

Variable correlation coefficient values were existed between pollinator population on chili and weather parameters of the experimental site (Table 3). Abundance of lime butterfly, honey bee and carpenter bee showed negative relationship with maximum and minimum temperatures, and positive relationship with relative humidity and rainfall. But significant correlation was found between the abundance of carpenter bee and maximum temperature. Sweat bee population showed positive but insignificant correlation with maximum and minimum temperatures, and insignificant negative correlation with relative humidity.

Table 3. Correlation coefficient (r) values between the abundance of the pollinator insects in chili ecosystem and weather parameters

Parameters	Maximum Temperature(˚C)	Minimum Temperature(˚C)	Relative humidity(%)	Rainfall (mm)
Lime butterfly	-0.139^{NS}	-0.067^{NS}	0.019^{NS}	0.090^{NS}
Honey bee	-0.327^{NS}	-0.476^{NS}	0.456^{NS}	0.197^{NS}
Carpenter bees	-0.974**	-0.701^{NS}	0.696^{NS}	0.994**
Sweat bee	0.128^{NS}	0.551^{NS}	-0.531^{NS}	0.007^{NS}
Max. Temperature (°C)		0.836^{NS}	-0.828^{NS}	-0.988**
Min. Temperature (°C)			-.999**	-0.759^{NS}
Relative humidity (%)				0.752^{NS}

NS Non-significant, * Significant, ** Highly significant.

Table 4. Impact of insect pollination on chili production

Parameters	Pollination conditions		
	Enclosed	Insect supplemented	Natural
Number of fruits per plant	165.2±3.1b	177.2±2.4a	168.8±2.2b
Fruit length (cm)	6.7±0.1c	7.4±0.1a	7.1±0.1b
Fruit diameter (mm)	7.2±0.1b	7.8±0.1a	7. 7±0.1a
Fruit weight (g)	2.22±0.05b	2.43±0.01a	2.33±0.01ab
Number of seeds per fruit	63.9±1.4b	72.1±0.5a	68.5±1.1a
Weight of 1000 seeds (g)	3.3±0.1b	4.5±0.1a	4.4±0.1a
Yield (t/ha)	14.7±0.1c	16.4±0.2a	15.6±0.1b
Yield increases due to insect pollination (t/ha)	-	1.65	1.13
Insect pollination exclusion reduced yield (%)	10.09	-	5.38
Insect pollination economic value (US$)	-	82.5	56.5
Crop vulnerability ratio	-	0.005	0.004

Price of green chili = 1 US$/kg

The effect of insect pollination on fruit and seed set, fruit and seed characteristics, yield, economic value and crop vulnerability ratio varied significantly (Table 4). Number of fruits per plant, fruit length (cm), fruit diameter (mm) and fruit weight (g) among the three pollination conditions varied from 165.2±3.1 to 177.2±2.4, 6.7±0.1 to 7.4±0.1, 7.2±0.1 to 7.8±0.1, 2.22±0.05 to 2.43±0.01, respectively and the results differed significantly among the three conditions. The number of seeds per fruit, weight of 1000 seeds (g) and yield (t/ha) of chili of the pollination conditions varied from 63.9±1.4 to 72.1±0.5, 0.32±0.01 to 0.46±0.01 and 14.7±0.1 to 16.4±0.2, respectively and the results differed significantly. Insect supplemented condition resulted significantly the highest number of fruits per plant, fruit length and weight, and yield. Fruit diameter, number of seed per fruit and weight of 1000 seeds were statistically similar in insect supplemented and natural pollination conditions. Increased yields due to insect pollination were 1.65 and 1.13 tons/ha in supplemented and natural conditions, respectively and insect pollination exclusion reduced yields in enclosed and natural conditions were 10.09% and 5.38%, respectively. Insect pollination economic value in insect supplemented condition was of 82.5 US$ and that was of 56.5 US$ in natural pollination condition. Chili plants revealed vulnerability ratio of 0.005 and 0.004 in insect supplemented and natural pollination condition, respectively.

Divergent pollinator insects and their varied level of abundance and visitation frequency carry out inconsistent pollination efficiency that consequently enumerates disparate quantity and quality of yields in various crops (Amin *et al*., 2019b). They also reported significant effect of supplemented insect pollinators on the yield and seed quality of eggplant. Naturally occurring pollinator insects contributed on the siliqua production and yield of mustard (Mandal *et al.*, 2018). Pudasaini *et al.* (2014) found 30%- 40% increased yield and higher weight of seeds in *A. cerana* and *A. mellifera* pollinated plants of rapeseed. Vishwakarma (2018) observed that number of seeds/fruit, fruit weight and 213.90% yield increased in chili due to honey bee pollination.

With supplemented insect pollinators, flowers get chance for pollination in the phase of fully functional generative organs thus produce increasing quantity and quality of fruits (Bieniasz, 2007; Bozek, 2012). Kwon and Saeed (2003) found the increase in fruit weight of 27.2% and number of seeds of 47.8% in capsicum due to pollinating by bees. Jacquemin (2017) reported insect pollination vulnerability scale from 0.0% to 41.1% and on average 11.1% for the crops that are used for human food.

The findings of this study showed that four species of pollinator insects visited the chili field and they exhibited distinctive foraging behavior. The pollinators were most abundant at 11.0 and 15.0 h of the day, and the daily maximum and minimum temperatures, relative humidity and rainfall affected their abundance. The pollinator insects revealed significant effect on quality and quantity of chili.

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