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Pollinator Diversity and Foraging Behavior in Chayote (*Sechium edule* Jacq)

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***Abstract*:** Chayote (*Sechium edule* Jacq.) is one of the important cucurbitaceous vegetables prominently grown in the northeastern Himalayan states. These crops prevail abundantly across this region however acquire little knowledge of their pollination. Information on pollinators is crucial for any crop; therefore, the study was conducted in the farmers' field to study the pollinators of chayote. The diversity of insect visitors was studied by observing the random flowers. The temporal abundance, foraging speed, and foraging rate were studied by observing twenty different flowers for 10 minutes. A total of nine species were recorded from the order Hymenoptera of which 3 species belonged to Apidae, 3 wasp species belonged to Vespidae and 1 species belonged to Halictidae. Shannon's diversity index (H), Simpson's diversity index and species richness (Margalef) were recorded as 2.131, 0.8741 and 1.782 respectively. The study revealed a significant relationship between foraging speed, species, day hours and species X day hours, while there was a non-significant relationship between foraging rate, species and day hours. The overall pollinators observed was 258 where highest pollination occurred during 9-11 hrs. The least time was spent during 15-17 hrs (6.74 seconds) while the frequency of foraging rate was highest during 15-17 hrs (10.83 flowers/minute).

***Keywords*:** Pollinator, Diversity, Foraging behavior, Chayote

Pollination, a vital aspect of the reproduction of flowering crops is given the greatest importance (Ollerton et al 2011, Giannini et al 2015). About 75% of crop species are pollinated by animals most of which are insect pollinators (Choi et al 2015, Siregar 2014). Chayote (*Sechium edule*) is a perennial monoecious climber in the Cucurbitaceae family which is an excellent source of nutrition (Kumar et al 2016, Stephens 2018). In India, it is widely cultivated in West Bengal, Tamil Nadu, Himachal Pradesh and the entire northeastern region for its tender shoots, fleshy pear-shaped fruits and tuberous roots (Yadav et al 2005, Rai et al 2006). It is one of the major vegetable crop grown in Sikkim and is consumed by both humans and animals. However, due to unknown diseases and other factors, chayote production has declined drastically in recent years. It bears a monoecious flower that requires sufficient entomophilous pollination to produce a substantial yield (Mukherjee et al 2019). It has been reported unsuitable for the cultivation of chayote under a greenhouse structure as the fruits fail to develop and drop before reaching maturity. (Bomfin et al 2016, Widhiono 2015). Chayote is cross-pollinated crop both the pistillate and staminate flowers are rich in nectar that attracts a variety of pollinators (Rojas-Sandoval 2020). Stingless bees of the genus *Trigona* are primary and efficient pollinators while wasps are among the secondary pollinators of chayote (Arnold et al 2018, Lira Saade 2020). Apart from the above insects *Apis mellifera* is also reported to pollinate the chayote plant (Soma Alvarez and Nunez Grajales 2013, Ricketts et al 2008, Reilly et al 2020). Pollinators such as *Apis dorsata, Apis cerana, Apis florea*, and *Trigona sp.* pollinate chayote in Bangalore, India (Mukherjee et al 2019). In the eastern Himalayan region of India, there is no information on chayote pollinators except the Indian bee (*Apis cerana* Indica). Considering the importance of insects in pollination of Chayote, the present study was undertaken to study the diversity, species richness and foraging behavior of pollinators of Chayote (*Sechium edule*).

MATERIAL AND METHODS

Study area: Sikkim is a fully organic state of India with an area of 7096 sq. km. and stretching 112 and 64 km from north to south and east to west, respectively. However, the habitable area is only 2500 sq. km. This Himalayan state lies between 27.45° N and 28.9° N latitudes and 87.59° east and 88.60° E longitudes. It accounts for about 0.05% of the total population and 0.22% of the geographical area of the country. The study was conducted in farmer's field of seven villages namely, Burikhop (West Sikkim), Pakki Goan (West Sikkim), Budhang (West Sikkim), Tsong (West Sikkim), Sang (East Sikkim), Sumik Lingee (East Sikkim), and Dzongu (North Sikkim) (Fig. 1).

Data collection: Visitors were captured using fine mesh

sweep nets and immobilized using ethyl acetate vapours. Experts from various universities and institutes identified the collected insect pollinators. Daily observations on random flowers were made to study the diversity of insect visitors. During the full bloom period, the temporal abundance, foraging speed and foraging rate of different insect visitors/pollinators were studied in twenty different chayote flowers for 10-minute intervals at 9:00-11:00 hrs, 12:00-14:00 hrs, and 15:00-17:00 hrs. Twenty individual species were observed to record the amount of time spent on each flower to study foraging speed, while foraging rate was recorded in terms of the number of flowers visited per minute through careful visual observation with a stopwatch (Dafni 2001).

Statistical analysis: The relative abundance of order, family, and species were used to calculate dominance. The Shannon diversity index (H'), Simpson Index, species richness (marglef) and evenness were calculated using the past 4 project software. The two-factor, completely randomized design was used to study variables such as foraging speed and rate. The two factors were species and day hours having 8 and 3 levels, respectively. Means were compared using the least significant difference test. The analysis was carried out with the help of the R package Doebio Research (Popat and Banukara 2020).

RESULTS AND DISCUSSION

A total of nine species were recorded, all belonging to the order Hymenoptera under 3 families of which 3 species belonging to Apidae (L*epidotrigona arcifera, Apis cerana, Bombus haemorroidalis*), five wasp species belonging to Vespidae (*Polistes carnifex*, *Eumenes fraternus*, *Pachodynerus sp.*, *Polybia sp.* and *Polistes Canadensis*), 1 species belonging to Halictidae (*Lasioglossum aeneiventre*) (Table 1). Rashmi et al (2014) also observed eight species of insects visitors of chayote flower belonging to the order Hymenoptera (Apidae, Halictidae, Specidae, Formicidae and Vespidae) and Diptera (Muscidae) of which major pollinator was *Trigona* sp. followed by *Apis cerena* belonging to order Hymenoptera.

Mukherjee et al (2019) found that *Apis cerana, Apis florea*, *Apis dorsata* and *Trigona* sp. are primary pollinators of chayote, all of which belong to the Hymenoptera order. Similarly, *Synoeca*, *Polybia,* and *Parachrataegus* wasps and smaller *Trigona* species are secondary pollinators. Similarly, Martínez-Bauer et al (202) recorded *A. mellifera* and *B. ephippiatus* are *S. edule* pollinators but also wasps such as *Polybia* species, *Polistes instabilis* and *V. squamosa*.

Vespidae was the most abundant family with six species contributing 51.54% of visitor abundance (Table 2). Among the pollinators species belonging to the vespidae, the highest relative abundance was recorded for *Polistes canadensis* (13.95%) followed by *Polistes carnifex* (13.57%) and *Pachodynerus sp.(9.30%)* and the least was *Eumenes fraternus* (5.81%). Family Apidae comprises 37.70% of relative abundance, where species *Apis cerana* recorded 17.83% abundance followed by *Lepidotrigona arcifera* (10.47%) and *Bombus haemorroidalis* (9.30%). *Lasioglossum aeneiventre* belonging to the Halticidae recorded, 10.85% of relative abundance. Among all the species irrespective of family the highest abundance was in species *Apis cerana* (17.83%) followed by *Polistes Canadensis* (13.95%) and *Polistes carnifex* (13.567%) *Lasioglossum aeneiventre* (12.36%). The least abundant was in *Eumenes fraternus* (5.81 %). This may be due to the wide domestication of *Apis cerana* by the farmers of Sikkim and its wide feeding preferences (Cui and Corlett 2016).

Shannon diversity index (H), Simpson diversity index, Berger-Parker index, and species richness (Margalef) values were 2.131, 0.874, 1.782, and 0.191, respectively (Table 3). This reflects the rich diversity of chayote, which is not dominated by a single species. This result is also reflected in the relative abundance of *Apis cerana*, which is followed by the other pollinator species. Bashir et al (2019) found a Shannon diversity index (H') of 3.97 and a Simpson diversity index of 0.93 in forest ecosystems. Alfawwaz et al (2022) reported a moderate Shannon diversity index (H') of 1.23. Eight pollinator species except *Eumenes fraternus* were identified as the main pollinators of chayote based on their abundance and foraging activity. Detailed observations were then made on these eight species. Pollinator foraging activity on chayote was greatly reduced during wind and intermittent rainfall but resumed again when conditions returned to normal. Sharma et al (2019) reported that the foraging activity of pollinators was negatively related to relative humidity and wind velocity. The highest relative abundance was recorded in *Apis cerana* (17.83%.), *Polistes Canadensis (*13.95%*), Polistes carnifex* (13.57%) followed by *Lasioglossum aeneiventre* (10.85%), and relative abundance was recorded in *Eumenes fraternus* (5.81%) (Table 4). Data on temporal variation in pollinator abundance (Table 5) showed that the highest number of insect visitors was recorded between 9:00-11:00 hrs (133 no.) followed by 12:00-13:00 hrs and 14:00-15:00 hrs. All the pollinator peak activities were observed between 9:00-11:00 hrs of the day and slowly decline towards evening. Thakur and Rana (2002) also found a significantly higher number of insect visitors during 9:00-10:00 hrs (3.88 insect/m^2/10 min) followed by 12:00-13:00 hrs and 15:00-16:00 hrs. Sharma et al (2019) also observed maximum bee visitors during 9:00-11:00 hrs, slightly low in 11:00-13:00 hrs and lowest in 15:00-16:00 hrs.

The higher activity of insect visitors during morning hours synchronizing with the opening of flowers was also reported by Sajjanar et al (2004). According to Widhiono (2015) humidity and light intensity also have a significant impact on pollinators. At optimal light intensity, pollinators begin foraging and stop activity at low light intensity. Malerbo-Souza et al (2021) reported *Trigona spinipes*, stingless bees as frequent and constant insects in chayote flowers between 8:00 and 13:00 hrs. Sharma et al (2019) found highest foraging activity of *Bombus haemorroidalis* and *Apis cerana* between 9:00-11:00 hrs. Mukerjee et al (2019) observed that pollinators were most active between 7:30 and 14:30 hrs. Rashmi et al (2014) observed the highest activity of chayote pollinators between 9:00-11:00 hrs followed by 7-9 hrs and 11-13 hrs, and very low activity between 17-18 hrs. Yunin et al (2019) observed stingless bee, *Heterotrigona itama*, and *Tetraponera laeviceps* visited both staminate and pistillate flowers, with peak visitation occurring between 8:30 and 10:30 hrs. Peak foraging time of *Halictus* sp. in Niger was observed at 12:00 hrs and *Ceratina* sp. in Mustard at 10:00 hrs (Navatha 2012).

The foraging speed shares an inverse relationship with the time spent per flower. The least amount of time spent was observed between 15:00-17:00 hrs (6.74 seconds/flower), followed by 12:00-14:00 hrs and 9:00-11:00 hrs (Table 5). Among the eight species included in the study, the lowest time spent per flower was observed for *Apis cerana* (3.97 sec/flower), followed by *Polybia* sp. which is at par with *P. canifex*, *B. haemorroidalis* and *P. Canadensis*. The interaction study showed that the least time spent was observed for *A. cerana* between 15:00-17:00 hrs (3.11 sec./flower), which was at par with *B. haemorroidalis* between 15:00-17:00 hrs (3.54 sec./flower). Thakur and Rana (2008) also found that bees spent the highest time during 9:00-10:00 hrs (11.83 seconds/flower), followed by 12:00-13:00 hrs. The longer time spent on the flower was also reported by Rana et al (2005). The abundance of pollen and nectar in freshly opened flowers could be the reason for the highest time per flower in the morning (Nepi et al 1996).

The foraging rate was observed highest during 15-17 hrs (10.83 flowers/minute), followed by 12:00-14:00 hrs and 9:00-11:00 hrs (Table 6). The highest number of flowers were visited by *Apis cerana* (11.94 flowers/minute), followed by

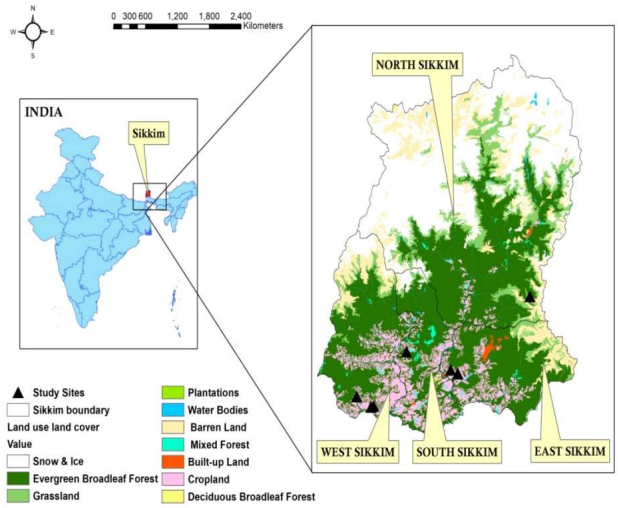

Fig. 1. Map depicting the study site

Table 1. Diversity of pollinators in chayote

Family	Common name	Scientific name	Species No.
Order Hymenoptera			
Apidae	Indian bee	*Apis cerana*	3
Apidae	Putka	*Lepidotrigona arcifera*	
Apidae	Bumble bee	*Bombus haemorroidalis*	
Halticidae	Sweat bee	*Lasioglossum aeneiventre*	1
Vespidae	Yellow paper	*Polistes carnifex*	5
Vespidae	Potter wasp	*Eumenes fraternus*	
Vespidae	Red paper wasp	*Polistes canadensis*	
Vespidae	Red and black mansion wasp	*Pachodynerus* sp.	
Vespidae	Social wasp	*Polybia* sp.	

Table 2. Insect visitor of chayote flower and their relative abundance

Family	Species	Total Species abundance (%)	Total family abundance (%)
Apidae	*Apis cerana*	17.83	37.60
	Lepidotrigona arcifera	10.47	
	Bombus haemorroidalis	9.30	
Halticidae	*Lasioglossum aeneiventre*	10.85	10.85
Vespidae	*Polistes carnifex*	13.57	51.54
	Eumenes fraternus	5.81	
	Polistes canadensis	13.95	
	Pachodynerus sp.	9.30	
	Polybia sp.	8.91	

Table 3. Diversity indices of insect pollinators of chayote

Diversity indices	
Shannon Index	2.131
Simpson Index	0.8741
Margalef	1.782
Berger-parker	0.191

Table 4. Temporal variation in pollinators relative abundance of chayote

Time (h)		9-11 hrs	12-13 hrs	14-15 hrs	Total
Relative abundance of pollinator	*Apis cerana*	15.79 (21)	17.39 (16)	27.27 (9)	17.83 (46)
	Lepidotrigona arcifera	9.77 (13)	10.87 (10)	12.12 (4)	10.47 (27)
	Bombus haemorroidalis	9.02 (12)	9.78 (9)	9.10 (3)	9.30 (24)
	Lasioglossum aeneiventre	12.03 (16)	10.87 (10)	6.06 (2)	10.85 (28)
	Polistes carnifex	13.53 (18)	13.04 (12)	15.15 (5)	13.57 (35)
	Eumenes fraternus	7.52 (10)	5.43 (5)	0.00 (0)	5.81 (15)
	Polistes canadensis	12.78 (17)	14.13 (13)	18.18 (6)	13.95 (36)
	Pachodynerus sp.	11.28 (15)	8.70 (8)	3.03 (1)	9.30 (24)
	Polybia sp.	8.27 (11)	9.78 (9)	9.09 (3)	8.91 (23)
	No of pollinator observed	133	92	33	258

Figure in the parenthesis are the number of insect observed

Table 5. Foraging speed of pollinators at different hours of the day (Sec/flower)

Pollinators	Time spent/flower (Sec)			Mean
	9:00-11:00 hrs	12:00-14:00 hrs	15:00-17:00 hrs	
A. cerana	4.50^{ijk}	4.32^{kl}	3.11^{m}	3.97^{e}
L. arcifera	15.07^{d}	13.12^{e}	9.45^{f}	12.55^{b}
B. haemorroidalis	5.28^{hi}	4.68^{ijk}	3.54^{lm}	4.50^{d}
Lasioglossum aeneiventre	29.23^{a}	25.06^{b}	20.66^{c}	24.98^{a}
P. carnifex	4.75^{ijk}	4.42^{ijk}	4.12^{ijk}	4.43^{dc}
Pachodynerus sp.	6.29^{g}	5.72^{gh}	4.82^{ijk}	5.61^{c}
P. Canadensis	5.21^{hij}	4.65^{ijk}	4.13^{kl}	4.66^{d}
Polybia sp.	4.60^{ijk}	4.34^{jkl}	4.12^{kl}	4.35^{dc}
Mean	9.37^{a}	8.29^{b}	6.74^{c}	
	Species	Day Hours	Species X Day Hours	
CD	0.51	0.31	0.88	
CV		9.45		

The same letter are statistically non-significant

Table 6. Pollinator foraging rate (flowers visited/min) at different hours of the day

Pollinators	Time spent/flower (Sec)			Mean
	9:00-11:00 hrs	12:00-14:00 hrs	15:00-17:00 hrs	
A. cerana	10.83	11.83	13.17	11.94^{a}
L. arcifera	1.22	1.55	2.18	1.65^{f}
B. haemorroidalis	8.50	9.66	11.53	9.90^{d}
Lasioglossum aeneiventre	0.97	1.22	1.78	1.32^{f}
P. carnifex	10.33	11.17	12.17	11.22^{b}
Pachodynerus sp.	7.00	8.50	10.17	8.56^{e}
P. Canadensis	9.83	10.33	12.00	10.72^{bc}
Polybia sp.	7.25	10.23	10.83	10.33^{cd}
Mean	9.33^{c}	10.23^{b}	10.83^{a}	
	Species	Day Hours	Species X Day Hours	
CD	0.70	0.43	NS	
CV		0.43		

The same letter are statistically non-significant

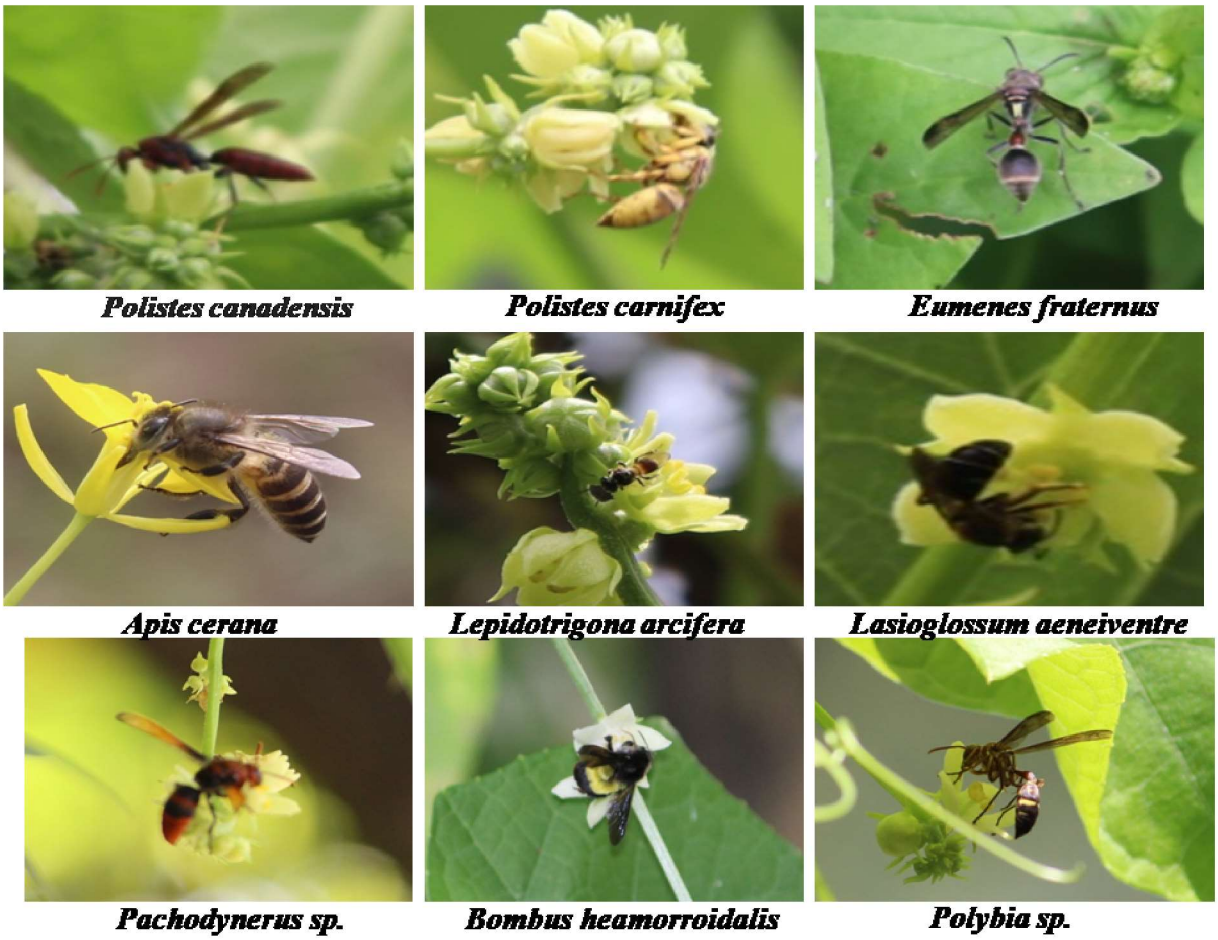

Fig. 2. Pollinators of chayote

Polistes carnifex which was at par with *P. canadensis* (10.72 flowers/minute) and the least flowers were visited by *Lasioglossum aeneiventre* which was at par with *L. arcifera*. Thakur and Rana (2008) observed the same pattern in the foraging rate. They found the highest foraging rate between 15:00-16:00 hrs (7.25 flowers/minute), followed by 12:00-13:00 hrs and 9:00-10:00 hrs. The reason for the high foraging rate in the afternoon followed by late afternoon could be due to insufficient nectar and pollen due to repeated visits. In the study of pollinators (*Apis cerana, Lasioglossum aeneiventre* and *Lepidotrigona arcifera*) of chayote some of the pollinators were also observed foraging in weeds such as *Ageratum conzoyoides* , *Ageratum houstonianum* , *Bidens pilosa*, *Persicara nepalensis*, *Solanum nigrum* , *Chenopdium album*, *Galingsoga parviflora* in Chayote area. Of the pollinators, *Apis cerana* was abundantly encountered foraging on *Bidens pilosa.*

CONCLUSIONS

Chayote production is in decreasing trend for the last observed decade in the eastern Himalayas of India due to diseases, pests, and other factors. Under these circumstances, a thorough study of pollinators is the need of the hour to recommend revival measures to increase the productivity of chayote. The present study has identified eight species of pollinators for Chayote, indicating high species richness in chayote. The foraging activities of pollinators were influenced by the time of the day. The highest pollinator activity was observed between 9:00 and 11:00 hrs. The honey bee (*Apis cerana*) was the most abundant pollinator of chayote but wasp species were more in number. Therefore, *Trigona* sp. has been reported as the most efficient pollinators of chayote. Further studies can be conducted to determine the efficiency level of pollinators of chayote.

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