POLLINATOR FAUNA, DIVERSITY AND THEIR ROLE IN ENHANCING YIELD IN CHILLI, *Capsicum annuum* L.

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In partial fulfilment of the requirements for the award of the degree of

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in

APICULTURE

BENGALURU **AUGUST, 2019**


Affectionately Dedicated
to My Father
Mr. Thathaiah,
Mother
Mrs. Gayithri Devi,
Sisters Nandu, Ambi
and My Guide

DEPARTMENT OF APICULTURE
UNIVERSITY OF AGRICULTURAL SCIENCES,
GKVK, BENGALURU-560065

CERTIFICATE

This is to certify that the thesis entitled **"POLLINATOR FAUNA, DIVERSITY AND THEIR ROLE IN ENHANCING YIELD IN CHILLI, *Capsicum annum* L."** submitted by **Miss. Chaitra, T., ID No. PALB 7219** in partial fulfilment of the requirement for the degree of **MASTER OF SCIENCE (Agriculture)** in **APICULTURE** to the University of Agricultural sciences, Bengaluru, is record of *bona-fide* research work done by her during the period of her study in this University under my guidance and supervision and no part of the thesis has been submitted for the award of any other degree, diploma, associateship, fellowship or any other similar titles.

Bengaluru
August, 2019

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(MOHAN RAO)

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POLLINATOR FAUNA, DIVERSITY AND THEIR ROLE IN ENHANCING YIELD IN CHILLI, *Capsicum annuum* L.

CHAITRA, T.

ABSTRACT

Studies on pollinator fauna, diversity and their role in enhancing yield in chilli was carried out during 2018-19 at the University of Agricultural Sciences, GKVK, Bengaluru. Anthesis was between 06:00h and 07:00h and pollen dehiscence was between 07:00h and 10:00h. Thirteen species of insect pollinators were recorded on chilli, of which ten species belonged to order Hymenoptera, one to Lepidoptera and two to Diptera. Among the pollinators, honey bees constituted 64.01 per cent. The peak foraging activity was observed between 09:00 AM to 11:00 AM of the day. Average fruit set (100.00 %), mean of single fruit weight (7.65g and 7.40g), mean fruit girth (1.18cm and 1.65cm), mean fruit length (8.95cm and 6.50cm), seeds capsule^{-1} (48.70 and 61.03) and mean seed weight (5.25g and 6.05g) were higher in eight visits flower^{-1} in case of *Apis dorsata* and *Tetragonula iridipennis*, respectively. The results of modes of pollination on quantitative parameters such as average fruit set, mean fruit weight, mean fruit girth, mean fruit length, seeds capsule^{-1} and mean seed weight and qualitative parameters such as moisture per cent, total soluble sugars, germination per cent and seedling vigour index were higher in open pollination.

August, 2019

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Dr. G. C. KUBERAPPA
(Major Advisor)

ಮೆಣಸಿನಕಾಯಿ ಬೆಳೆಯಲ್ಲಿ ಪರಾಗಸ್ಪರ್ಶಿ ಕೀಟಗಳ ವೈವಿಧ್ಯತೆ ಮತ್ತು ಇಳುವರಿ ವೃದ್ಧಿಸುವಿಕೆಯಲ್ಲಿ ಅವುಗಳ ಪಾತ್ರ

ಚೈತ್ರ, ಟಿ.

ಪ್ರಬಂಧ

ಮೆಣಸಿನಕಾಯಿ ಬೆಳೆಯಲ್ಲಿ ಪರಾಗಸ್ಪರ್ಶಿ ಕೀಟಗಳ ವೈವಿಧ್ಯತೆ ಮತ್ತು ಇಳುವರಿ ವೃದ್ಧಿಸುವಿಕೆಯಲ್ಲಿ ಅವುಗಳ ಪಾತ್ರದ ಕುರಿತಾಗಿ ಕೃಷಿವಿಶ್ವವಿದ್ಯಾಲಯದ, ಜಿ. ಕೆ. ವಿ. ಕೆ. ಆವರಣದಲ್ಲಿ 2018–19 ರ ಸಾಲಿನಲ್ಲಿ ಸಂಶೋಧನೆಯನ್ನು ಕೈಗೊಳ್ಳಲಾಗಿತ್ತು. ಮೆಣಸಿನಕಾಯಿಯಲ್ಲಿ ಹೂ ಅರಳುವಿಕೆ ಸುಮಾರು 6 ರಿಂದ 7 ಗಂಟೆಯ ಒಳಗಾದರೆ, ಪರಾಗವಿಘಟನೆಯು ಸುಮಾರು 7 ರಿಂದ 10 ಗಂಟೆಯವರೆಗೆ ಗಮನಿಸಲಾಯಿತು. ಸುಮಾರು ಹದಿಮೂರು ಜಾತಿಯ ಕೀಟ ಪರಾಗಸ್ಪರ್ಶಿಗಳನ್ನು ಮೆಣಸಿನಕಾಯಿಯಲ್ಲಿ ದಾಖಲಿಸಲಾಗಿದೆ. ಅವುಗಳಲ್ಲಿ ಹತ್ತು ಪ್ರಭೇದಗಳು ಹೈಮೆನೋಪ್ಟೆರಾ ಗುಂಪಿಗೆ ಸೇರಿದರೆ, ಒಂದು ಲೆಪಿಡೊಪ್ಟೆರಾ ಮತ್ತು ಎರಡು ಪ್ರಭೇದಗಳು ಡಿಪ್ಟೆರಾ ಗುಂಪಿಗೆ ಸೇರಿರುತ್ತವೆ. ಮೆಣಸಿನಕಾಯಿಗೆ ಬೇಟಿನೀಡಿದ ಪರಾಗಸ್ಪರ್ಶಿಗಳಲ್ಲಿ ಜೇನುಹುಳುಗಳು ಶೇಕಡ 64.01 ರಷ್ಟಿವೆ. ಸುಮಾರು ಬೆಳ್ಳಗೆ 9 ರಿಂದ 11 ರವರೆಗೆ ಪರಾಗಸ್ಪರ್ಶಿಗಳ ಹೆಚ್ಚಿನ ಕಾರ್ಯಚಟುವಟಿಕೆಗಳನ್ನು ಗಮನಿಸಲಾಯಿತು. ಹೆಜ್ಜೇನು ಹಾಗೂ ನಸುರು ಜೇನಿನ ಪ್ರತಿ ಹೂವಿಗೆ 8 ಜೇನುನೊಣಗಳ ಭೇಟಿಯಲ್ಲಿ ಕ್ರಮವಾಗಿ ಕಾಯಿಕಟ್ಟುವಿಕೆ (100. 00%) ಕಾಯಿಯ ತೂಕ (7.65ಗ್ರಾಂ ಮತ್ತು 7.40ಗ್ರಾಂ), ಕಾಯಿಯ ಉದ್ದ (8.95 ಸೆ.ಮಿ. ಮತ್ತು 6.50 ಸೆ.ಮಿ.), ಕಾಯಿಯ ಸುತ್ತಳತೆ (1.18 ಸೆ.ಮಿ. ಮತ್ತು 1.65 ಸೆ.ಮಿ), ಪ್ರತಿಕಾಯಿಯ ಬೀಜಗಳ ಸಂಖ್ಯೆ (48.70% ಮತ್ತು 61.03%) ಮತ್ತು ಬೀಜದ ತೂಕ (5.25ಗ್ರಾಂ ಮತ್ತು 6.05ಗ್ರಾಂ) ಗರಿಷ್ಟವಾಗಿರುತ್ತದೆ. ಪರಾಗಸ್ಪರ್ಶದ ವಿವಿಧ ವಿಧಾನಗಳ ಫಲಿತಾಂಶಗಳಲ್ಲಿ ಪರಿಮಾಣತ್ಮಕ ನಿಯತಾಂಕಗಳಾದ ಕಾಯಿಕಟ್ಟುವಿಕೆ, ಕಾಯಿಯ ತೂಕ, ಕಾಯಿಯ ಸುತ್ತಳತೆ, ಕಾಯಿಯ ಉದ್ದ ಪ್ರತಿಕಾಯಿಯ ಬೀಜಗಳ ಸಂಖ್ಯೆ ಮತ್ತು ಬೀಜದ ತೂಕ ಹಾಗೂ ಗುಣಾತ್ಮಕ ನಿಯತಾಂಕಗಳಾದ ತೇವಾಂಶ, ಟಿಎಸ್ಎಸ್, ಮೊಳಕೆಯೊಡುಯುವಿಕೆ ಮತ್ತು ಮೊಳಕೆ ಹುರುಪಿನ ಸೂಚ್ಯಂಕ ಮುಕ್ತ ಪರಾಗಸ್ಪರ್ಶ ಕ್ರಿಯೆಯಲ್ಲಿ ಗರಿಷ್ಟವಾಗಿರುತ್ತದೆ.

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ಕೃಷಿ ವಿಶ್ವವಿದ್ಯಾಲಯ, ಜಿಕೆವಿಕೆ, ಬೆಂಗಳೂರು – 65

Pollinators' fauna, diversity and their role in enhancing the yield in Chilli (*Capsicum annum* L .)

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INTRODUCTION:

Chilli, *Capsicum annum* L. is an important solanaceous crop of tropics and sub tropics. Chilli is produced throughout India and it is the largest producer of chilli in the world there by making our country the most dominating player in the world market. The major chilli growing states in India are Andhra Pradesh, Karnataka, Orissa, WestBengal, Maharashtra, Gujarat and Tamil Nadu and in all the union territories. India produces 9,89,140 MT tonnes of chilli from an area of 9,11,200 hectares (Annonymous, 2017).

Chilli plant is an often cross pollinated crop need pollination by insect pollinators. Though the crop is economically important, information regarding the role of pollination in fruit set is very limited. In this context, the present study was undertaken with the following objectives.

OBJECTIVES:

1.The abundance and diversity of insect visitors of chilli flower.

2. Foraging activity of insect pollinators

MATERIALS AND METHODS:

1. The abundance and diversity of flower visitors of chilli.

The major flower visitors of chilli were recorded by visual scanning and sweep net collection. The collected insects were killed, mounted and identified by insect taxomist, Department of Entomology, UAS, GKVK. Bengaluru.

2. Foraging activity of insect pollinators.

The foraging activity of the most frequent flower visitors were recorded by closely observing the foraging bees from 6:00 to 18:00 hours for 10 minutes per 5 flowers at an hourly interval throughout the blooming period of chilli.

RESULTS:

The flowers of Chilli were visited by 12 species of insects belonging to 3 orders and 6 families. Out of 12 species, 6 species belongs to family apidae and 2 species to halictidae of order hymenoptera. Each 1 species from papilionidae and pieridae belongs to order lepidoptera and each 1 species from syrphidae and sarcophagidae of order diptera were also recorded on chilli flower.(Table.1).

The major flower visitors were *Apis dorsata* (24.31%), followed by *Apis mellifera* (17.61%), *Tetragonula irridipennis* (15.70%), *Apis cerana* (13.75%), Haictidae (11.52%) and others (17.08%) (table.2).

Table No 1. Flower Visitors of Chilli

Sl No.	Pollinator species	Order	Family
1.	*Apis dorsata*	Hymenoptera	Apidae
2.	*Apis florea*	Hymenoptera	Apidae
3.	*Apis cerana*	Hymenoptera	Apidae
4.	*Apis mellifera*	Hymenoptera	Apidae
5.	*Tetragonula irridipennis*	Hymenoptera	Apidae
6.	*Ceratina binghami*	Hymenoptera	Apidae
7.	*Halictus* sp.	Hymenoptera	Halictidae
8.	*Nomia* sp.	Hymenoptera	Halictidae
9.	Citrus butterfly	Lepidoptera	Papilionidae
10.	Sulphur butterfly	Lepidoptera	Pieridae
11.	*Sarcophaga* sp.	Diptera	Sarcophagidae
12.	*Syrphus* sp	Diptera	Syrphidae

(a) *Apis dorsata* visiting chilli flower

(b) *Apis cerana* visiting chilli flower

Table No 2. Foraging activity of insect pollinators

Number of insect pollinators/5 flowers/10 minutes							
Time	Ac	Ad	Am	Ti	halictus	Others	Total
06:00-06:10	0.70	1.64	1.57	0.70	0.71	0.72	6.06
07:00-07:10	0.75	2.10	1.62	0.70	0.72	1.75	7.65
08:00-08:10	1.48	2.30	1.89	0.70	0.74	1.78	8.91
09:00-09:10	1.60	2.61	1.69	0.84	1.28	1.82	9.86
10:00-10:10	1.85	2.63	2.18	1.59	1.60	1.97	11.84
11:00-11:10	1.64	2.47	2.38	1.84	1.85	1.90	12.11
12:00-12:10	1.71	2.83	2.02	1.63	1.88	1.92	12.01
13:00-13:10	1.62	2.51	1.93	1.86	1.86	1.80	11.61
14:00-14:10	1.48	2.12	1.86	1.60	1.58	1.6	10.34
15:00-15:10	0.75	1.83	0.82	1.80	1.30	1.49	8.01
16:00-16:10	0.71	1.70	0.73	0.72	0.71	1.11	5.72
17:00-17:10	0.70	1.60	0.71	0.70	0.71	0.87	5.32
18:00-18:10	0.70	1.44	0.71	0.70	0.71	0.70	4.99
Total	15.75	27.84	20.16	15.46	15.71	19.57	114.52
% of bee visit	13.75	24.31	17.61	15.70	11.52	17.08	
mean	1.21	2.14	1.55	1.18	1.20	1.50	1.46
	time			BEES			
	SEM	0.345644		SEM	0.072159		
	CD	0.958076		CD	0.200014		

*Ad- *Apis dorsata*, Ac- *Apis cerana*, Am- *Apis mellifera*, Ti- *Tetragonula iridipennis*.

DISCUSSION:

The peak foraging activity of insect pollinators was observed in the morning hours from 10:00 to 12:00 hrs and the activity of insect pollinators was gradually decreased from 13:00hrs onwards during the study period. There was a significant difference between the pollinator activity over different time interval.

The activity of *A. dorsata* was noticed throughout the day from 09.00 to 17.00hrs with more abundance between 10.00 to 12.00hrs of the day. Similarly, *Apis mellifera* was more abundant between 10.00 to 11.00hrs. Whereas, *Tetragona irridipennis* between 11.00 to 12.00 hrs and *A. cerana* between 11.00 to 12.00 hrs of the day.

SUMMARY:

The flower visitors of both Apis and non-Apis bees are important in fruit set of chilli to obtain higher production and among these species honey bees were found to be major pollinators and played a major role in the chilli production. Hence, this study suggested to incorporate the services of bees to get higher yield in chilli crop.s

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I INTRODUCTION

Chilli, *Capsicum annuum* L. is the most widely used universal spice. It is an important tropical and subtropical solanaceous vegetable cum spice crop, native to Brazil and introduced into India in sixteenth century by the Portuguese. *C. annum* is the dominant cultivated species all over the world along with four other domesticated species viz., *C. baccatum, C. chinense, C. frutescens* and *C. pubescens*. It is grown all over the world owing to its high consumption, nutritional and commercial value both in developed and developing countries. Chilli biodiversity conservation and sustainability of species and cultivars etc., has enormous importance, owing to the significance of the crop (Bosland and Votava, 2000; Wang and Bosland, 2006 and Ince *et al.*, 2010).

India is the world's largest producer, consumer and exporter of chilli. Capital investments in cold storage in the chilli growing areas give sustained production and market share for Indian chilli. In the world, area of chilli is around 20.20 million hectares with the production of 37.62million tonnes. The largest producer of chillies in the world is India accounting for 13.76 million tonnes annually, followed by China with a production of around 3 million tonnes. Out of the total world chilli production (37.62 million tonnes), 36.57 per cent is contributed by India, followed by China 7.97 per cent. The world trade in chilli account for 18 per cent of the total spice trade in the world occupying second position after black pepper. The major chilli growing states in India are Andhra Pradesh, Karnataka, Orissa, West Bengal, Maharashtra, Gujarat and Tamil Nadu and in all union territories. Andhra Pradesh is the largest producer in the country with an area of 2 lakh hectares and production of 9.9 lakh tonnes. According to the Spices Board, India is exporting its major share to Malaysia, followed by Sri Lanka, Bangladesh, Pakistan, Indonesia and China (Anonymous, 2017).

Chilli is a very popular vegetable not only in India, but all over the world. India is known as "The Home of Spices". Indian meal is not considered as complete without the tangy and delectable flavor of spices. Indian spices are famous all over the world for their gastronic value because they possess high medicinal values. Though Indian exports are showing satisfactory trends, now a days India is facing very tough competition in the

international export market as price of Indian chilli powder is considered too high, whereas other competitive countries are providing chilli at very competitive rates to the major importing countries. Necessary steps have to be taken by the Government in encouraging the exporters to maintain the Indian dominance in the world market (Anonymous, 2017).

Chilli is affected by number of pests normally aphids, thrips, leaf hoppers, ear wigs, crickets, mites, root grubs, pod borers, cut worms, flea beetles and diseases like damping off, anthracnose and bacterial wilt which were major constraints for chilli production (Faisal Hussain and Muhammad Abid, 2011).

Chilli is a pollinator dependent crop (Cauich *et al.* 2006) and in the Yucatan Peninsula, its flowers were visited by a number of bee species including native *Augochloropsis* sp., *Exomalopsis* sp., *Nannotrigona perilampoides* Cresson, *Frieseomelitta nigra* Cresson, *Lasioglossum* sp. and the introduced honey bee, *A. mellifera* (Palma *et al.* 2008). Chilli cultivation has even been suggested to maintain diverse and abundant pollinator assemblage in the Neotropics (Macias Macias *et al.*, 2009). But, no information is available in India on pollinators fauna, their foraging behaviour and their role in increasing fruit set in chilli. Hence, the present study is under taken with the following objectives,

1. The abundance and diversity of flower visitors of chilli.
2. Foraging behaviour of insect pollinators.
3. The different modes of pollination on fruit set and yield parameters.

II REVIEW OF LITERATURE

The literature pertaining to "Pollinators fauna, diversity and their role in enhancing yield in chilli, *Capsicum annuum* L." has been reviewed in this chapter.

2.1 Floral biology

The genus *Capsicum* is often cross pollinated and natural cross pollination may go up to 50 per cent depending upon the extent of style exertion, time of anther dehiscence, wind direction and insect pollination (Murthy and Murthy, 1962; Hosmani, 1993).

The nectary was present on the basal part of the ovary as swellings in chilli. The nectariferous cells were smaller and denser than the neighbouring parenchyma. Stomata were present in the nectary epidermis, but did not present on the other parts of the ovary epidermis (Rabinowitch, *et al.*, 1993).

Sumardi (1993) conducted study in Australia reported that the longevity of the female gametophyte in the Longum group of *C. annuum* (chilli) was short lived.

Chilli (*C. annuum* L.) was one of the crops where time of anthesis and dehiscence, pollen viability and germination and stigma receptivity changes over the different locations (Kalloo, 1994).

Chilli flowers were smaller in size (10-15 mm), campanulate to *rotate* flower type with depth to flower base 2 mm and hence, chilli pepper needs smaller pollinators for pollination of crop. Further, he reported that there was increase in the yield of chilli due to introduction of *Trigona minangkabau* and *T. leaviceps* (Bosland and Votava, 2000).

Aleemullah *et al.* (2000) recorded that five per cent of flowers opened before sunrise, while ninety per cent of flowers required 6–9 h to open. Pollen dehiscence occurred by longitudinal splitting of the anthers after one hour of the flower opening in *C. annuum*. The flowers of capsicum were pendulous, bisexual, anthers were tubular and dehisce occurred along lateral slit (Raw, 2000).

Dhall *et al.* (2011) reported that stigma remained receptive for 24 hours after anthesis and pollination of flower was necessary, when flowers were open completely or latest by 12 hours after opening to get maximum fruit set and hybrid seed yield. The anthesis time was recoded between 5.39 AM to 6.29 AM and pollen dehiscence between 7.34 AM to 8.13 AM.

2.2 The abundance and diversity of flower visitors of chilli.

2.2.1 Floral visitors of chilli.

The botanical diversity, morphology, degree of self-compatibility and sexuality of the flowers of crops grown required a diversity of insect pollinators for efficient pollination (Williams 1994, 1996).

The study was conducted on Insect biodiversity in mixed cropping of chilli and onion crops revealed that honey bees, solitary bees and wasp were the major pollinators of *capsicum* sp. (Tanksley, 1985).

O' Toole (1993) reported that wild bee species were better pollinators compared to *A. mellifera* in most of the Solanaceous crops.

Stingless bees were smaller in size (2-14 mm) which enabled bees to access various flowers with very narrow opening that could not be accessed by other bees. Therefore, *Trigona sp*. is the appropriate pollinator of chilli for increasing yield (Sakagami *et al.*, 1985; Osawa and Tsubaki, 2003).

Frequency and duration of visit by pollinators to nectariferous crops depend on nectar production level. Generally, biotic pollinators need physical contact with reproductive organ of flower for effective pollination (Nicolson *et al.*, 2005; Graham *et al.*, 2006).

Stingless bees, *Trigona minangkabau* and *T. leaviceps* were found to be effective pollinator in chili and because of their smaller body size, when obtaining nectar their heads could enter up to the base of flower and their legs contact with pollen and hence,

effective pollination occurred in crop. Further, stingless bees tend to showed flower constancy and therefore, bees visited same flower repeatedly during foraging (Slaa *et al.*, 2006).

Thirty-nine species of insect pollinators were recorded in chilli at Mexico. Among them, two native bees namely *Exomalopsis* sp. and *Augochloroapis* sp. and one introduced bee species, *Apis mellifera* were found effective in pollination of chilli. Bees transferred pollen between recently opened flowers by making them better for selfing and outcrossing within the same plant, while solitary bees were more efficient for pollen collection in older flowers and its transference between different plants (Greenleaf and Kremen, 2006b; Macias-Macias *et al.,* 2009 and Klein *et al.*, 2008).

Chilli was a pollinator dependent crop and pollinator dependency per cent of chilli ranged from 32 % to 37% (Cauich *et al.*, 2006 and Carr and Davidar, 2015).

Wanigasekara and karunaratne (2012) recorded *Amegilla comberi, Xylocopa tenuiscapa, Haplonomia westwoodi* and *Patllapis kaluterae* were buzzing bees and *Trigona irridipenis, Ceratina hieroglyphica* and *Apis dorsata* were non-buzzing bees in *Solanum* sp.

The pollinator dependency and pollinators visitation rates to flowers of six vegetable crops namely brinjal, tomato, chilli, okra, bitter and snake gourds at Coimbatore region of southern India revealed that *Apis cerana*, *A. florea*, *A. dorsata, Heterotrigona iridipennis,* solitary bees *Xylocopa, Ceratina, Amegilla,* wasps and *Nomia* were major pollinators among Hymenoptera, whereas butterflies and moths of order Lepidopteran and *Syrphid* flies of order Diptera were minor pollinators (Carr, 2012, Carr and Davidar, 2015 and Ollerton *et al.* 2014).

The native pollinator species belong to genus *Exomalopsis* and *Xylocopa* were efficient pollinators of tomato in open field (Mariana *et al.*, 2014).

Patricia *et al.* (2017) reported that sweat bees of genus *Lasioglossum* were the most abundant bee taxon in chilli fields during the study conducted on Sweat bees on hot chillies.

2.2.2 Foraging activity of the insect pollinators

Pollinators made selective floral visit based on their energy need and further, the prevailing weather conditions regulates the foraging dynamics which leads to the schedule of pollinators activities (Heinrich and Raven, 1972; Heinrich, 1975, 1983; Abrol, 1986, 1992, 2005).

The pollinators such as *Tetragonisca angustula* and *Apis mellifera* spent mean of 18.7 and 17.9 seconds per flower to collect pollen and 13.5 and 9.5 seconds to collect nectar in summer squash (Quagliotti, 1979).

The foraging rate by individual bee was enhanced, when it found profitable flower patches (major nectar source), but turns down, when it assesses low profitability from its forage (Seeley and Levien, 1987; Seeley *et al.*, 1991).

Abrol (1992) reported that temperature, light intensity including day and night differences, cloudiness, floral reward and relative humidity were predominant environmental factors affecting foraging activity of bees. The interaction of these factors influence the physiological and metabolic processes of plants as well as the pollinators which resulted in effective pollination.

The attraction of honey bees to the foraging sources was due to interplay of several factors, off which olfactory rather than visual cues generated by nectar and pollen grains were the key factors (Kaur and Sihag, 1994; Sharma and Bichoo, 1996; Omoloye *et al.*, 2002 a, b).

Tootland and Matthews (1994) reported more pollinators visitation during early in the flowering season and reduced activity as the season progressed. The pollinators visitation was positively correlated with daily mean flower density. The flower density of individual species also affected visitation activity.

The foraging activity of bumble bees (*Bombus terrestris* L.) during sunny days on eggplant from 8:00AM and ended at 5:00PM with maximum activity between 1:00PM and 5:00PM, whereas in cloudy days, the foraging activity started at 11:00AM and ends before 5:00PM visiting only 3 flowers per minute (Abak *et al.*, 1995).

Wilson and Stine (1996) in *Solanum melongena* reported that bumble bees foraged on same species of flower often preferred by individual bees on which they are already foraging. They suggested that constancy is due to some form of perceptual conditioning whereby individual bees become temporarily sensitized to one or few floral cues.

Study carried out on the honey bee activity, abundance and pollination efficiency of honey bees on carrot and onion flowers indicated that the nectar production was optimum during the midday, whereas the honey bee activity reached the peak during the midday (Priti and Sihag, 1998).

Goulson (1999) reported that the insect pollinators foraging behavior was the complex and flexible due to small reward provided by patchily distributed flowers with space and time which has been erratically depleted by other foragers.

The positive relationship exists between the diversity and density of floral resources and diversity and density of pollinators as per field study (Steffan-Dewenter *et al.*, 2002; Klein *et al.*, 2003; Potts *et al.*, 2003, 2004; Westphal *et al.*, 2003).

Greenleaf and Kremen (2006) recorded the *Bombus* sp. from Apidae and an un-identified species from Halictidae on the flower of tomato crop. The abundance of wild bees was more in the tomato crop grown in field.

Macias-Macias *et al.* (2009) reported that *Capsicum chinense* flowers produce nectar and hence, honey bees were frequent in this cultivar. Nectar production also explain the higher bee diversity in *Capsicum chinense*, since both nectar and pollen gatherers were present on this crop at one time.

2.3 The different modes of pollination on fruit set and yield parameters.

Bailey (1891) reported that artificial pollination on vegetable crops always resulted in fewer seeds than natural pollination even when an excess of pollen was applied. He stated that with hand pollination a few seeds were produced at the apex of the fruit, but most of the ovules remained undeveloped.

Jones and Rosa (1928) reported that plants grown in a screened house isolated from insects were non-fruitful and that flowers emasculated and left to natural pollination rarely set fruit. This indicated that the plant is not self-fruitful and insects were required to transfer the pollen to the stigma in appropriate amount and at the right time.

Both self and cross pollination in sweet peppers, *C. annuum* indicated that, 71% of crossed flowers developed into fruits, 46% of developed fruits in self-pollination and only 20% of flowers set fruits in control. (Martin and Crawford, 1951; Murthy and Murthy, 1962; Erwin, 1932; Sampson, 1936; Free, 1970)

The pollination of brinjal flowers through contact, gravity and wind resulted in 30 to 40 per cent fruit set, 0.7 to 15 per cent fruit set through manual crossing and rest was due to insect pollination (Sambandam, 1964).

The different varieties of vegetable produces valuable seed or fruits through honey bee cross pollination and the low quality with lesser yields were obtained due to insufficient pollination (Chang, 1990).

Chilli, *C. annuum* was one of the most important glasshouse crops benefitted from bee pollination and number of different bee species including the European honey bee (*Apis mellifera* L.), bumble bees (*Bombus* spp.) and neotropical and Asian stingless bees (Apidae: Melliponinae) shown increased fruit quality and /or yield. (De Ruiter *et al.*, 1991; Dag and Kamer, 2001; Higo *et al.*, 2004; Roldan Serrano and Guerra-Sanz, 2006; De Oliveira Cruz *et al.*, 2005; Amano, 2002).

Greco *et al.* (2011) reported that when *Trigona carbonaria* was enclosed in one glasshouse and another as a control for pollination of *C. annuum*. The grade and weight

of fresh fruit increased by 26% and 24%, respectively for plants subjected to bee pollination.

Shipp *et al.* (1994) reported that pollination of sweet pepper using bumble bee (*Bombus impatiens*) had showed significant difference in fruit weight, fruit width, fruit volume, pericarp volume, seed weight and days from fruit set to harvest between sweet peppers produced from bee pollination and without bee pollination.

The bumble bees and honey bees were frequently used to enhance the fruit set in different vegetable crops (Paydas *et al.*, 2000).

Cruz *et al.* (2005) reported that stingless bee, *Melipona subnitida* was efficient species to increase fruit weight, number of seeds and to reduce fruit malformation, when compared to sweet pepper cultivation under greenhouse condition without bees.

Gemmill-Herren and Ochieng (2008) studied the efficiency of different pollination on two eggplant varieties. For both of them, a positive influence of bumble bee pollination on the quality of eggplant fruits was confirmed. Fruits with significantly larger seed number was achieved in plants where flowers were pollinated by insects as compared to those set due to self-pollination or inflorescence vibrating.

In the Yucatan Peninsula, the presence of native bees in chilli crop fields shown increased crop yield and quality (Macias-Macias *et al.* 2009).

To ascertain the receptivity of stigma, per cent fruit set was taken as an index. The maximum fruit set (44.47%) was observed when pollinated at the time of anthesis and declined thereafter. Fruit set was also found better (30.08%) when pollinated at 12 hours after anthesis. On the other hand, delayed pollination (24 hours after anthesis) resulted in drying up of stigmatic surface and reduced fruit set (11.86%) in chilli (Dhall *et al.*, 2011).

The study on pollination deficit in open-field tomato crops (*solanum lycopersicum* L.) reported that number of seeds were higher for fruits originated from open-pollination compared to self-pollination (Macias-Macias *et al.* 2009; Mariana *et al.*, 2014).

Chilli fruits produced from *H. itama* pollination were significantly heavier, longer and contained greater number of seeds per fruit than self-pollination. Number of seed produced from self-pollination (48.54±15.28), Hand pollination (102.92±24.25) and *H. itama* pollination (112.54±21.15) (Azim et al, 2016).

Lasioglossum sp. recorded as one of the most abundant pollinator in chilli fields in contrast to other bee species in tropical Mexico underlining the importance of wild bees in crop pollination (Garibaldi *et al.*, 2013, 2016 and Patricia *et al.*, 2017).

The study on chilli pollination in green house with *Trigona carbonaria* and control found that chilli fruit diameter was less affected by any increase in pollination and the seed production and fruit length was increased by bee pollination (De Oliveira Cruz *et al.*, 2005 and Patricia *et al.*, 2017).

Farag *et al.* (2019) reported that bumble bee pollination increased number of fruits per plant, healthy fruits, fruit length, fruit breadth, fruit weight, fruit yield, number of seeds and 1000 seed weight by 38.41, 21.94, 46.45, 50.82, 57.66, 64.79, 78.54 and 78.80 %, respectively in sweet pepper under greenhouse condition.

III MATERIALS AND METHODS

The floral biology, insect pollinators diversity, pollinators abundance, foraging activity, number of bee visits and effect of different modes of pollination on quantitative and qualitative parameters in chilli, *Capsicum annum* L. was carried out at 'K' block, Gandhi Krishi Vignana Kendra, University of Agricultural Sciences, Bengaluru during 2018-2019 which is located at altitude of 930 m, latitude of 13° N and longitude of 77°35' E situated in the south eastern dry zone of Karnataka state. Chilli Hybrid KBCH-1 was sown by following the recommended package of practices. Materials utilized and methodology followed for the present investigation are mentioned in this chapter.

3.1 Phenology and floral biology of chilli.

Commencement of flowering, anthesis, longevity of individual flowers and flower duration was recorded in detail by tagging randomly chosen ten plants and observed the development of hundred labelled buds. Floral parts such as sepals, petals, stamens, anthers, ovary, style, stigma from ten randomly selected flowers were removed and counted. The flower structure, time of anthesis, pollen dehiscence, structure of pollen, pollen viability, pollen to ovule ratio and receptivity of the stigma was also recorded.

3.2 The abundance and diversity of flower visitors of chilli

3.2.1 Insect pollinators diversity

Ten plants were selected randomly to record different species of insect pollinators visiting the flowers daily throughout the blooming period from 06:00 to 18:00 h of the day at hourly interval for 10 minutes. All insect visitors of chilli flowers were collected by using sweep net. Pollinators visiting chilli crop were collected, preserved and identified with the help of Taxonomist, Department of Entomology, GKVK, Bengaluru.

3.2.2 Shannon weiner diversity index

The frequency of visits by each species was recorded to identify the most abundant species effecting chilli pollination. Pollinator count data was used to compute Shannon-Weaver index of diversity (H) using the following formula

$$H = - pi \ln pi$$

Where,

Pi= the proportion of the i^{th} species of pollinator

3.2.3 Abundance of insect pollinators

The relative abundance of the different insect pollinators visiting chilli flower were recorded from 06:00 to 18:00 h at an hourly interval for 10 minutes throughout blooming period on randomly selected ten plants and expressed as mean number of pollinators visited per flower per 10 minutes.

3.3 Foraging activity of insect pollinators on chilli

The foraging activity of honey bee species and other pollinators on flowers for collecting pollen or nectar under open field condition was observed throughout flowering period. The observations were recorded on randomly selected ten flowers from 06:00 to 18:00 h at an hourly interval for ten minutes and expressed as the mean numbers of foragers per flower per 10 minutes.

3.3.1 Time spent by honey bees on chilli for nectar and pollen collection

The time spent by different species of honey bees viz., *A. cerana*, *A. dorsata*, *T. iridipennis* and *A. mellifera* on the flower from landing to till take off was recorded by using stop watch and considered as time spent by the bee per flower. The observations were recorded from 06:00 to 18:00 h at an hourly interval for 10 minutes during flowering period on ten randomly selected chilli flowers. The mean time spent by each bee was expressed in seconds per flower.

3.3.2 Effect of number of honey bees visit on chilli on some quantitative parameters

Ten flower buds were selected randomly to find out the effect of number of bee visits separately for *A. cerana indica* and *A. dorsata*. These buds were bagged using butter paper cover, a day prior to flower opening and each flower was exposed to 0, 1, 2, 3, 4, 5, 6, 7 and 8 bee visits, immediately after flower opening. The flowers were immediately rebagged and retained for one day. The observations were recorded on

quantitative parameters such as flower drop, fruit set, fruit weight, fruit length, fruit girth, number of seeds per fruits and seed weight.

3.4 Effect of honey bee pollination on quantitative and qualitative improvement in chilli

The effect of different honey bee species *A. cerana*, *A. dorsata*, *T. iridipennis* and *A. mellifera* pollination in chilli on qualitative parameters viz., flower drop, fruit set, fruit weight, fruit length, fruit girth, number of seeds per fruits and seed weight and qualitative parameters like moisture, TSS, per cent seed germination were assessed and compared among the treatments. The experiment had seven treatments with six replication laid out in randomized block design with the following treatments (plate 1 and 2).

T1- Open pollination

T2-Pollination with *A. cerana*

T3-Pollination with *A. dorsata*

T4-Pollination with *T. iridipennis*

T5- Pollination with *A. mellifera*

T6-Hand pollination

T7-Control

In case of open pollination, all the species of pollinators were allowed to visit the chilli flowers, whereas in case of pollination with *A. cerana*, *A. dorsata*, *T. iridipennis* and *A. mellifera* a day before flower opening, flower buds were covered with butter paper. The butter papers were removed on the day of flower opening and particular species of honey bee visiting the chilli flowers was carefully watched, tagged and again covered with butter paper. In case of hand pollination, the flower buds were tagged on previous day of flower opening and pollinated on the next morning. In case of control, the plants were covered with nylon mesh (1 mm size) and no pollinators were allowed to visit the flowers. Ten flower buds were tagged in each treatment for further studies.

3.4.1 Quantitative parameters of chilli

3.4.1.1 Flower drop

The flower drop was estimated by counting the number of flowers dropped from sampled flowers for each treatment and per cent flower drop was worked out.

3.4.1.2 Fruit set

The fruit set was estimated by counting the number of fruits set out of sampled flowers for each treatment and expressed in percentage.

3.4.1.3 Fruit weight

The ten matured fruits were selected and harvested from each treatment and weighed immediately. The mean fruit weight was calculated and expressed in grams.

3.4.1.4 Fruit length

Ten tagged matured fruits were harvested from each treatment to record the length. The mean length was calculated and expressed in centimeters.

3.4.1.5 Fruit girth

Ten tagged matured fruits were harvested from each treatment to record the girth of the fruit. By using the thread and scale calculated girth. The mean girth was calculated and expressed in centimeters.

3.4.1.6 Number of seeds/capsule

The ten tagged matured fruits were harvested from each treatment and counted the number of sound seeds per capsule and expressed as mean number of seeds per capsule.

3.4.1.7 Seed weight

Thousand seeds from harvested dried fruits were counted to record the weight using electronic digital balance and mean seed weight was expressed in grams.

Plate 1: Experimental plot

Plate 2: Experimental plot with control treatment

3.4.2 Qualitative parameters of chilli

3.4.2.1 Moisture content

The fresh weight of ten matured fruits from each treatment was taken and same were dried in the hot air oven to a constant weight at a temperature of 60±1° and again weighed. The per cent moisture in the fruit was estimated by using the formula.

$$\text{Moisture content (\%)} = \frac{\text{Weight of fruit after drying}}{\text{Fresh weight of the fruit}} \text{X } 100$$

3.4.2.2 Total sugar content (TSS)

Ten selected matured fruits from each treatment were taken and grinded individually. The liquid extract of the fruit was separated and a drop was placed on hand refractometer to record the TSS content of the fruit and expressed in percentage.

3.4.2.3 Seed germination

Seeds obtained from different treatments were subjected to germination tests. The germination test was conducted as per the procedure of ISTA by using top paper method at temperature of 25-30°C and 90-95 per cent relative humidity. After eight days, first count of seedlings was taken and germination percentage was worked out the number of healthy seedlings obtained in the test.

3.4.2.4 Seedling vigour index

Seedling obtained after germination from each treatment was taken and were dried in the hot air oven at a temperature of 60±1°C and weighed. The seedling vigour index was calculated by using the formula.

Seedling vigour index = dry weight of seedlings x germination percentage

IV RESULTS AND DISCUSSION

The present study was conducted on Pollinators fauna, diversity and their role in enhancing the yield in Chilli, *Capsicum annum* L. The results and discussion on floral biology, insect pollinators and their abundance, foraging activity, effect of number of bee visits and different modes of pollination on quantitative and qualitative improvement of chilli hybrid KBCH-1 has been presented in this chapter.

4.1 Phenology and floral biology of chilli.

Chilli is an annual, herbaceous plant grows upright to about 1-1.5 meter. Leaves ovate, tapering to a sharp point, dark green on the upper surface and pale green on the lower surface. Flowers were creamy white in colour, actinomorphic, pedicellate, pentamerous and hypogynus (Plate 3). Crop was started to flower 40-45 days after planting and 50% flowering was observed on 60 to 65 days after planting. Chilli flowers were borned at the axil of the first branching node in clusters of 2-3. The flower was complete with calyx, corolla, androecium and gynoecium. Petals 5, broad, campanulate, ribbed, about 2-3 cm long and truncate or undulate to weakly or prominently dentate. Chilli flower consist of 5 stamens and pistil comprised an ovary that was 2-5 mm long and 1.5-5 mm in diameter. Style was 3.5-6.5 mm long and capitate stigma was slightly wider than the style. The nectaries appears as swellings on the basal part of the ovary (Table 1).

Anthesis started by morning at 06:00 h onwards and maximum flower opening up to 89 percent was observed between 06:00 hr to 07:00 hr of the day (Table 2). Flowers were remained open for maximum of 3 days. Stigma was receptive for twenty-four hours. Anther dehiscence was started from 07:00 h onwards and maximum anther dehiscence up to 52 per cent occurred between 09:30 and 10:00 hr (Table 3). The number of pollen grains per flower ranged from 90,000 to 53,000 with mean of 72900 and the number of ovules per flower ranged from 122 to 210 with mean of 139.10 (n=10). Mean pollen to ovule ratio was found to be 533.30. Pollen grains to one ovule per flower ranged between 409 and 654 (Table 4).

Table 1: Floral biology of chilli

Plant and flower characteristics	Parameters
Plant height (m)**	1-1.5
Number of flowers / axil**	2-3
Number of flowers / plant**	500-600
Flower colour*	Creamy white
Sepals*	5
Petals *	5
Length of corolla (mm)*	2-3
Length of ovary (mm)*	2-5
Length of style (mm)*	3.5-6.5
Number of stamens *	5
Location of Nectaries *	Base of the ovary
Forage available*	Pollen and nectar
Flowering period*	October- December
Fruit	Capsule
Sowing date	22nd June 2019
Mean of first flower opening (days)	N=25, 42.5±3.23

Note: *Mean of ten flowers, ** Mean of ten plants

Table 2. Anthesis of chilli flower

Time of the day	Number of flowers opened
6:00-6:15 hrs	30
6:15-6:30 hrs	24
6:30-6:45 hrs	20
6:45-7:00 hrs	15
7:00-7:15 hrs	4
7:15-7:30 hrs	4
7:30-7:45 hrs	2
7:45-8:00 hrs	1
Mean ±SD	12.5±11.26
N	100

Table 3. Time of anther dehiscence in chilli

Time of the day	Number of flowers dehisced	Per cent dehiscence
7:00-7:30 hrs	6	12
7:30-8:00 hrs	4	18
8:00-8:30 hrs	6	12
8:30-9:00 hrs	8	16
9:00-9:30 hrs	8	16
9:30-10:00 hrs	18	36
Mean±SD	8.33±4.97	18.33±8.98
Total	50	50

Table 4. Pollen to ovule ratio in chilli

Sl. No.	Pollen number	Ovule number	Pollen to ovule ratio
1	90000	170	529:1
2	85000	130	654:1
3	75000	130	576:1
4	86000	210	409:1
5	74000	130	569:1
6	66000	122	540:1
7	53000	123	430:1
8	64000	124	516:1
9	72000	127	566:1
10	64000	125	544:1
Mean±SD	72900±11637.58	139.10±28.59	
Range	**137000-284000**	**122-210**	**206-304:1**

Plant

Flower

Plate 3: Chilli plant and flower

The present study on floral biology of chilli are in conformity with the findings of Aleemullah *et al.* (2000) where they found that 5% of flowers were opened before sunrise, whereas 90% of flowers were opened from 6 hr to 9 hr after dawn. Anther dehiscence followed by the liberation of pollen grains was occurred by the longitudinal splitting of the anthers with dehiscence commencing 1 hr after flower opening in *C. annuum*. The chilli anthesis was completed by 0900 h as per the findings of the Quagliotti (1979). Dhall *et al.* (2011) reported that though the stigma remained receptive for 24 hours after anthesis, it was necessary to pollinate the flower when they were completely open or latest 12 hours after opening to get maximum fruit set and hybrid seed yield and also reported that anthesis and pollen dehiscence timing was 5.39 am to 6.29 a.m. and 7.34 am to 8.13 a.m., respectively. The slight variation in the some of the characters may be due to variation in the type of crop, soil fertility and climatic conditions of the experimental site.

4.2 Insect pollinators diversity and their abundance in chilli.

4.2.1 Insect pollinators diversity

Thirteen species of insect pollinators were recorded during flowering period of chilli. Among them, ten species belonged to order Hymenoptera, one to order Lepidoptera and two to Diptera. Hymenopterans consisted of ten species, of which seven species from family Apidae (*Apis dorsata* Fab., *Apis florea* Fab., *Apis cerana* Fab., *Apis mellifera* Fab., *Tetragonula iridipennis* Smith, *Amegilla zonata* Linn. and *Ceratina binghami* Cockerell), two species from halictidae (*Halictus ligatus* Say. and *Nomia irridisence* Smith), one from Vespidae (*Vespula vulgaris* Linn.). Dipteran consisted of one species each from Sarcophagidae (*Sarcophaga sp.*) and Syrphidae (*Syrphus* sp.). Lepidoptera consisted of one species from Pieridae (*Belenois aurota* Fab) (Table 5 and plate 4,5 and 6).

Similar report on pollinator dependency and pollinators visitation rates to flowers of six vegetable crops namely brinjal, tomato, chilli, okra, bitter and snake gourds at Coimbatore region of southern India. *A. cerana, A. florea, A. dorsata, Heterotrigona iridipennis* and solitary bees viz., *Xylocopa, Ceratina, Amegilla*, wasps and *Nomia* were

major pollinators among Hymenoptera, whereas the Lepidopterans such as butterflies, moths and *Syrphid* flies of order Dipteran were minor pollinators (Carr, 2012, 2015 and Ollerton *et al.* 2014). Wanigasekara and karunaratne (2012) recorded *Amegilla comberi, Xylocopa tenuiscapa*, *Haplonomia westwoodi* and *Patllapis kaluterae* were buzzing bees and *Trigona irridipenis, Ceratina hieroglyphica* and *A. dorsata* were non-buzzing bees in *Solanum* sp. Macias-Macias *et al.* (2009) recorded the 39 species of insect pollinators visiting chilli *(C. chinense)* at Mexico. Among them, two native bees *Exomalopsis* sp. and *Augochloroapis* sp. and one introduced bee species *A. mellifera* were major pollinators. Palma *et al.* (2008) reported that chilli flowers were visited by native bee species namely *Augochloropsis* sp., *Exomalopsis* sp., *Nannotrigona perilampoides, Lasioglossum* sp. and the introduced honey bee, *A. mellifera*. However, the slight variation in pollinators fauna in the present study may be due to soil type, climatic condition and species and variety of the chilli grown.

Table 5. Diversity of insect pollinators of chilli

Sl. No.	Pollinator species	Family	Order
1.	*Apis dorsata* Fab.		Hymenoptera
2.	*Apis florea* Fab.		
3.	*Apis cerana* Fab.		
4.	*Apis mellifera* Fab.	Apidae	
5.	*Tetragonula iridipennis* Smith		
6.	*Ceratina binghami* Cockerell		
7.	*Amegilla zonata* Linn.		
8.	*Halictus ligatus* Say		
9.	*Nomia irridisence* Smith	Halictidae	
10.	*Vespula vulgaris* Linn.	Papilionidae	Vespidae
11.	*Belenois aurota* Fab.	Pieridae	Lepidoptera
12.	*Sarcophaga* sp.	Sarcophagidae	Diptera
13.	*Syrphus* sp.	Syrphidae	

***Apis dorsata* Fab.**

***Apis cerana* Fab.**

***Apis florea* Fab.**

***Tetragonula iridipennis* Smith**

Plate 4: Insect pollinators of chilli

***Ceratina binghami* Cockerell**

***Halictus ligatus* Say**

***Vespula vulgaris* Linn.**

***Amegilla* zonata Linn.**

Plate 5: Insect pollinators of chilli

***Nomia irridisence* Smith**

***Syrphus* sp.**

***Belenois aurota* Fab.**

Plate 6: Insect pollinators of chilli

4.2.2 Shannon wiener diversity index

The data on abundance of bee species and their diversity before noon and after noon of the day were used to calculate the Shannon-wiener diversity index. The pollinators diversity was high during before noon (H=2.27) and decreased by after noon (H=2.21) (Table 6).

4.2.3 Relative abundance of insect pollinators visiting chilli.

The relative abundance of different insect pollinators visiting chilli flowers differed significantly during different hours of the day throughout the blooming period of chilli crop. The number of insect pollinators were increased from 0800 h onwards and reached maximum between 10:00 to 12:00 h of the day. But, the numbers of pollinators were decreased after 13:00 h up to the end of the day during the study period.

Among the pollinators visited chilli, the abundance of honey bee species constituted 64.01 per cent. Among the honey bee species in the order hymenoptera, the per cent relative abundance of *A. dorsata* was maximum (20.45%), followed by *A. mellifera* (17.58%), *T. iridipennis* (15.05%) and *A. cerana* (10.93%), whereas the *Halictus ligatus* constituted 16.58 per cent of the total pollinators visited the flowers of chilli. Similarly, the relative abundance of other pollinators was 19.46 percent (Table 7 and fig 1 and 2).

The results obtained in present study was on par with study conducted by Dag and Kamer (2001) on *C. chinense* who reported that increased pollination was recorded by high abundance of honey bees and stingless bees.

4.2.4 Foraging activity of insect pollinators in chilli

Foraging activity of different insect pollinator varied significantly during different days of flower opening during study period.

Table 6. Shannon-wiener diversity index of flower visitors of chilli during fore-noon and after-noon hours of the day

Pollinators sp.	Fore-noon				After-noon			
	Ni	Pi	ln.	-(Pi*ln Pi)	Ni	Pi	Ln	-(Pi*ln Pi)
Apis dorsata Fab.	40	0.25	-1.38	-0.35	22	0.24	-1.42	-0.34
Apis cerana Fab.	11	0.07	-2.65	-0.19	9	0.10	-2.30	-0.23
Apis mellifera Fab.	24	0.15	-1.89	-0.29	16	0.17	-1.77	-0.31
Tetragonula iridipennis Smith	18	0.11	-2.20	-0.25	13	0.14	-1.96	-0.28
Halictus ligatus Say	10	0.06	-3.50	-0.22	7	0.08	-2.52	-0.19
Nomia irridisence. Smith	8	0.05	-2.99	-0.15	3	0.03	-3.50	-0.11
Ceratina binghami Cockerell	7	0.04	-3.21	-0.14	2	0.02	-3.91	-0.09
Amegilla zonata Linn.	11	0.07	-2.65	-0.19	5	0.05	-2.99	-0.16
Vespula vulgaris Linn.	2	0.01	-4.60	-0.06	2	0.02	-3.91	-0.09
Belenois aurota Fab.	1	0.01	-4.60	-0.03	2	0.02	-3.91	-0.09
Sarcophaga sp.	13	0.08	-2.52	-0.21	5	0.05	-2.99	-0.16
Syrphus sp.	12	0.08	-2.52	-0.19	6	0.07	-2.65	-0.17
Total	157			H=-2.27	92			H=-2.21

Table 7. Relative abundance of pollinators in chilli

Time (Hrs)	Relative abundance of bees (no of bees/flower/10min)						
	Ad	***Ac***	***Am***	***T.i***	***Halictus ligatus***	**Others**	**Total**
06:00	1.70 (1.48)	0.20 (0.83)	0.90 (1.18)	0.90 (1.18)	0.70 (1.90)	2.70 (1.79)	7.10
07:00	2.70 (1.79)	0.30 (.89)	2.20 (1.64)	2.10 (1.61)	1.90 (1.54)	2.60 (1.76)	11.80
08:00	3.20 (1.92)	1.60 (1.44)	3.10 (1.89)	2.60 (1.76)	2.60 (1.76)	3.30 (1.94)	16.40
09:00	3.80 (2.07)	2.30 (1.67)	2.90 (1.84)	3.20 (1.92)	2.90 (1.84)	3.40 (1.97)	18.50
10:00	4.60 (2.25)	3.20 (1.920	4.60 (2.25)	2.30 (1.67)	3.30 (1.94)	3.80 (2.07)	21.80
11:00	3.60 (2.02)	2.50 (1.73)	5.50 (2.44)	2.90 (1.84)	3.40 (1.97)	2.80 (1.81)	20.70
12:00	3.20 (1.92)	2.40 (1.70)	3.30 (1.94)	2.00 (1.58)	3.20 (1.92)	2.80 (1.81)	16.90
13:00	3.10 (1.89)	2.10 (1.61)	2.70 (1.79)	2.50 (1.73)	2.70 (1.79)	2.60 (1.76)	15.70
14:00	2.50 (1.73)	1.90 (1.54)	2.80 (1.81)	2.40 (1.70)	2.50 (1.73)	2.00 (1.58)	14.10
15:00	2.50 (1.73)	0.70 (1.09)	0.90 (1.18)	1.50 (1.41)	1.90 (1.54)	2.30 (1.67)	9.80
16:00	2.10 (1.61)	0.70 (1.09)	0.60 (1.04)	1.80 (1.51)	1.80 (1.51)	2.20 (1.64)	9.20
17:00	1.30 (1.34)	0.50 (1.00)	0.20 (0.83)	1.30 (1.34)	1.10 (1.26)	2.10 (1.61)	6.50
18:00	0.50 (1.00)	0.20 (0.83)	0.20 (0.83)	0.10 (0.77)	0.20 (0.83)	0.40 (0.94)	1.60
Mean	2.68	1.43	2.30	1.97	2.17	2.54	170.1
SEM	0.28	0.23	0.24	0.25	0.24	0.19	
CD-5%	0.79	0.65	0.66	0.70	2.82	0.52	
TOTAL	34.8	18.6	29.9	25.6	28.2	33	170.1
PERCENT COMPOSITION	20.45	10.93	17.58	15.05	16.58	19.46	100

Note: *Ad- Apis dorsata, Ac- Apis cerana, Am- Apis mellifera, T.i- Tetragonula iridipennis.*

#figures in the parenthesis are $\sqrt{x + 0.5}$ transformed value

Maximum number of *A. cerana*, *A. dorsata*, *A. mellifera* and *T. iridipennis* were recorded at 10:00 and 12:00 h (2.93 and 2.33, 7.06 and 7.13, 4.66 and 3.46 and 4.50 and 4.50 and 5.25 bees/plant/ 10 min, respectively), but the number of *Halictus* sp. and other pollinators were recorded at 12:00 and 13:00 h (3.20 and 3.00 and 3.13 and 2.66 bees/plant/10 min, respectively) during fifteen days after flowering. Similarly, the number of *A. cerana*, *A. dorsata*, *A. mellifera* and *T. iridipennis* were maximum at 10:00 to 12:00h (2.86 and 2.20,6.86 and 7.46, 3.06 and 2.73 and 1.93 and 2.20 bees/plant/10 min, respectively), whereas *Halictus* sp. and other pollinators were recorded at 12:00 and 13:00 h of the day (3.00 and 3.13 and 2.86 and 3.60 bees/plant/10min, respectively) during thirty days after flowering (Table 8 and fig 3 and 4).

Maximum number of *A. cerana*, *A. dorsata*, *A. mellifera* and *T. iridipennis* were recorded at 10:00 and 12:00 h (3.06 and 2.73, 6.13 and 7.93, 4.40 and 3.86 and 2.06 and 2.26 bees/plant/ 10 min, respectively), but the number of *Halictus* sp. and other pollinators were recorded at 12:00 and 13:00 h (3.06 and 3.00 and 2.86 ad 2.33 bees/plant/ 10 min, respectively) during forty-five days after flowering. Maximum number of *A. cerana*, *A. dorsata*, *A. mellifera* and *T. iridipennis* were recorded at 10:00 and 12:00 h (2.86 and 2.86, 6.20 and 7.60, 4.20 and 3.33 and 2.06 and 2.00 bees/plant/ 10 min, respectively) but the number of *Halictus* sp. and other pollinators were recorded at 12:00 and 13:00 h (3.06 and 2.86 and 4.60 and 3.40 bees/plant/ 10 min, respectively) during sixty days after flowering (Table 9 and fig 5 and 6).

Maximum number of *A. cerana*, *A. dorsata*, *A. mellifera* and *T. iridipennis* were recorded at 10:00 and 12:00 h (5.62 and 4.37, 6.46 and 7.33, 4.13 and 6.67 and 2.00 and 1.93 bees/plant/ 10 min, respectively) but the number of *Halictus* sp. and other pollinators were recorded at 12:00 and 13:00 h (3.00 and 3.00 and 4.00 and 2.53 bees/plant/ 10 min, respectively) during seventy-five days after flowering (Table 10 and fig 7 and 8). Maximum number of *A. cerana*, *A. dorsata*, *A. mellifera* and *T. iridipennis* were recorded at 10:00 and 12:00 h (3.00 and 2.33, 6.00 and 8.00, 4.46 and 3.26 and 3.62 and 3.75 bees/plant/ 10 min, respectively) but the number of *Halictus* sp. and other pollinators were recorded at 12:00 and 13:00 h (3.13 and 3.00 and 2.20 and 2.33 bees/plant/ 10 min, respectively) during ninety days after flowering.

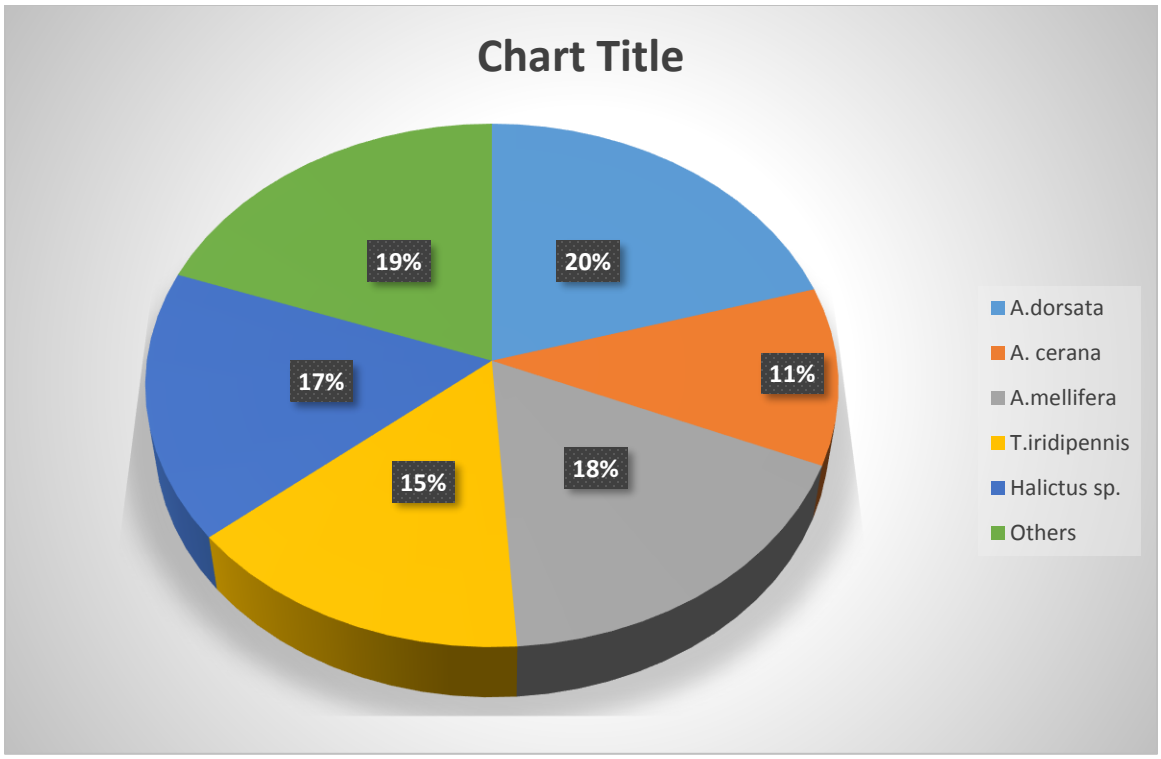

Fig. 1: Per cent species composition of insect pollinators

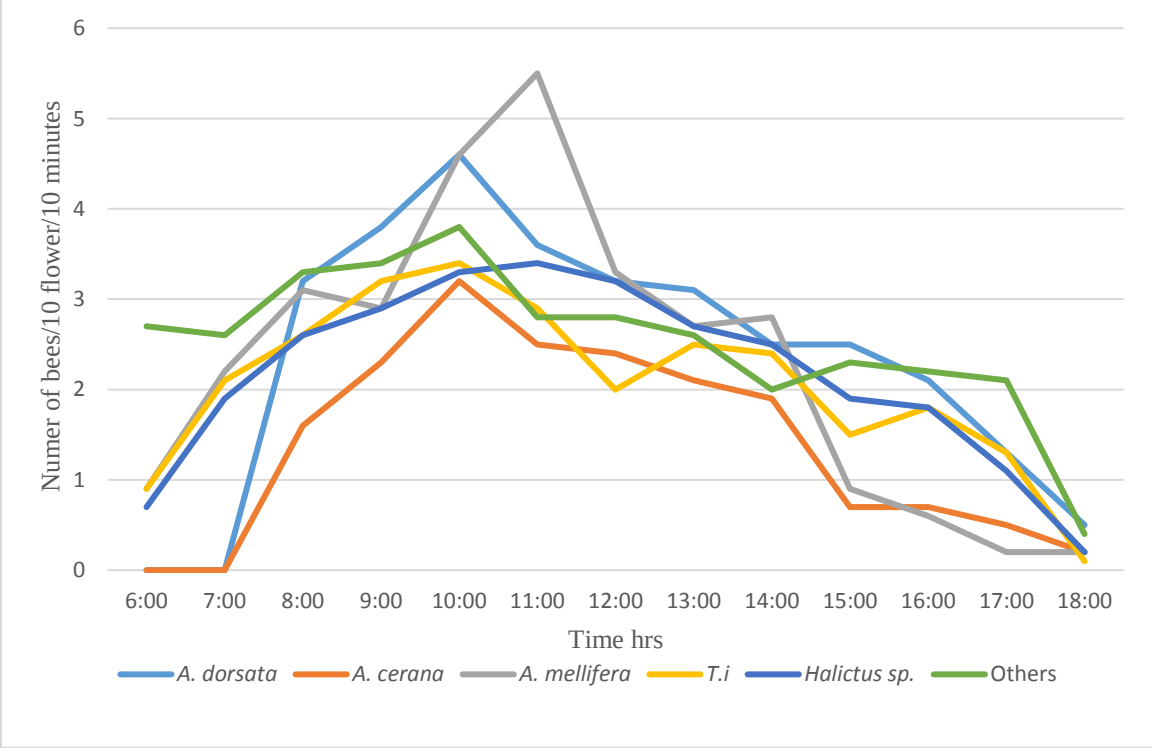

Fig. 2: Relative abundance of insect pollinators

Table 8. Foraging activity of insect pollinators during 15 DAF and 30 DAF of chilli under open condition. (number of insect pollinators/flower/10 minutes)

Time (Hrs)	15 DAF						30 DAF					
	Ac	***Ad***	***Am***	***T.i***	***Halictus* sp.**	**Others**	***Ac***	***Ad***	***Am***	***T.i***	***Halictus* sp.**	**Others**
06:00-06:10	0.00 (071)	2.46 (1.72)	1.26 (1.32)	0.00 (0.71)	0.00 (0.71)	0.20 (0.83)	0.00 (0.71)	2.33 (1.68)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
07:00-07:10	0.00 (0.71)	4.00 (2.12)	2.20 (1.64)	0.00 (0.71)	0.00 (0.71)	2.53 (1.74)	0.26 (0.87)	3.66 (2.04)	0.13 (0.79)	0.00 (0.71)	0.00 (0.71)	2.93 (1.85)
08:00-08:10	1.33 (1.35)	5.33 (2.41)	3.13 (1.90)	0.00 (0.71)	0.20 (0.83)	2.80 (1.81)	1.66 (1.47)	4.93 (2.33)	2.26 (1.66)	0.00 (0.71)	0.00 (0.71)	2.93 (1.85)
09:00-09:10	1.93 (1.55)	7.20 (2.77)	3.26 (1.94)	1.62 (1.45)	1.33 (1.35)	3.26 (1.94)	2.13 (1.62)	6.33 (2.61)	2.13 (1.62)	0.40 (0.94)	1.06 (1.25)	3.86 (2.08)
10:00-10:10	2.93 (1.85)	7.06 (2.75)	4.66 (2.27)	4.50 (2.23)	2.26 (1.66)	3.86 (2.08)	2.86 (1.83)	6.86 (2.71)	3.06 (1.88)	1.93 (1.55)	2.06 (1.60)	3.20 (1.92)
11:00-11:10	2.33 (1.68)	6.33 (2.61)	5.66 (2.48)	6.25 (2.59)	3.06 (1.88)	3.26 (1.94)	2.60 (1.76)	5.46 (2.44)	2.00 (1.58)	2.73 (1.80)	2.86 (1.83)	3.20 (1.92)
12:00-12:10	2.33 (1.68)	7.13 (2.76)	3.46 (1.99)	5.25 (2.39)	3.20 (1.92)	3.13 (1.90)	2.20 (1.64)	7.46 (2.82)	2.73 (1.80)	2.20 (1.64)	3.00 (1.87)	2.86 (1.83)
13:00-13:10	2.00 (1.58)	5.60 (2.46)	2.93 (1.85)	6.00 (2.54)	3.00 (1.87)	2.66 (1.77)	2.00 (158)	5.53 (2.45)	2.06 (1.60)	3.06 (1.88)	3.13 (1.90)	3.60 (2.02)
14:00-14:10	1.53 (1.42)	4.13 (2.15)	2.86 (1.83)	4.25 (2.17)	2.00 (1.58)	2.06 (1.60)	1.60 (1.44)	3.86 (2.08)	2.13 (1.62)	2.13 (1.62)	2.00 (1.58)	2.67 (1.78)
15:00-15:10	0.26 (0.88)	3.06 (1.88)	1.13 (1.27)	5.37 (2.42)	1.20 (1.30)	1.73 (1.45)	0.06 (0.75)	2.66 (1.78)	0.20 (0.83)	2.60 (1.76)	1.46 (1.40)	2.33 (1.68)
16:00-16:10	0.13 (0.80)	2.53 (1.74)	0.40 (0.94)	0.25 (0.87)	0.00 (0.71)	1.53 (1.42)	0.00 (0.71)	2.20 (1.64)	0.00 (0.71)	0.13 (0.79)	0.00 (0.71)	0.20 (0.83)
17:00-17:10	0.00 (0.71)	1.86 (1.53)	0.13 (0.80)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	1.86 (1.54)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	2.33 (1.68)
18:00-18:10	0.00 (0.71)	1.26 (1.32)	0.13 (0.80)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71	1.67 (1.47)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
MEAN	**1.13**	**4.46**	**2.40**	**2.57**	**1.25**	**2.08**	**1.18**	**4.22**	**1.28**	**1.17**	**1.20**	**2.32**
SEM	**0.03**	**0.05**	**0.06**	**0.05**	**0.03**	**0.01**	**0.04**	**0.05**	**0.05**	**0.04**	**0.03**	**0.02**
CD@5%	**0.10**	**0.14**	**0.18**	**0.13**	**0.08**	**0.02**	**0.11**	**0.14**	**0.14**	**0.12**	**0.08**	**0.07**

Note: Ad- *Apis dorsata*, Ac- *Apis cerana*, Am- *Apis mellifera*, *T.i- Tetragonula iridipennis*. DAF- Days after flowering

Figures in the parenthesis are $\sqrt{x + 0.5}$ transformed value.

Table 9. Foraging activity of insect pollinators during 45 DAF and 60 DAF chilli under open condition (number of insect pollinators/flower/10 minutes)

Time (Hrs)	45 DAF						60 DAF					
	Ac	***Ad***	***Am***	***T.i***	***Halictus* sp.**	**Others**	***Ac***	***Ad***	***Am***	***T.i***	***Halictus* sp.**	**Others**
06:00-06:10	0.00 (0.71)	2.26 (1.66)	1.80 (1.51)	0.00 (0.71)	0.13 (0.79)	0.00 (0.71)	0.00 (0.71)	2.33 (1.68)	2.53 (1.74)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
07:00-07:10	0.13 (0.79)	3.93 (2.10)	2.06 (1.60)	0.00 (0.71)	0.20 (0.83)	2.80 (1.81)	0.13 (0.79)	3.93 (2.10)	2.06 (1.60)	0.00 (0.71)	0.00 (0.71)	3.86 (2.08)
08:00-08:10	2.26 (1.66)	4.86 (.31)	3.26 (1.94)	0.00 (0.71)	0.26 (0.87)	2.80 (1.81)	2.13 (1.62)	4.86 (2.31)	3.06 (1.88)	0.00 (0.71)	0.00 (0.71)	3.00 (1.87)
09:00-09:10	2.13 (1.62)	6.40 (2.62)	2.46 (1.72)	0.20 (0.83)	1.46 (1.40)	3.20 (1.92)	2.26 (1.66)	6.26 (2.60)	2.20 (1.64)	0.13 (0.79)	1.20 (1.30)	2.53 (1.74)
10:00-10:10	3.06 (1.88)	6.13 (2.57)	4.40 (2.21)	2.06 (1.60)	2.20 (1.64)	4.60 (2.25)	2.86 (1.83)	6.20 (2.58)	4.20 (2.16)	2.06 (1.60)	2.00 (1.58)	3.26 (1.94)
11:00-11:10	2.00 (1.58)	5.67 (2.48)	5.46 (2.44)	2.93 (1.85)	2.93 (1.85)	3.80 (2.07)	2.13 (1.62)	5.40 (2.42)	5.06 (2.35)	2.86 (1.83)	3.06 (1.88)	2.93 (1.85)
12:00-12:10	2.73 (1.79)	7.93 (2.90)	3.86 (2.08)	2.26 (1.66)	3.06 (1.88)	2.86 (1.83)	2.86 (1.83)	7.60 (2.84)	3.33 (1.95)	2.00 (1.58)	3.06 (1.88)	4.60 (2.25)
13:00-13:10	2.06 (1.60)	6.13 (2.57)	3.06 (1.88)	2.93 (1.85)	3.00 (1.87)	2.33 (1.68)	2.33 (1.68)	5.80 (2.50)	3.40 (1.97)	2.86 (1.83)	2.86 (1.83)	3.40 (1.97)
14:00-14:10	2.13 (1.62)	4.33 (2.19)	3.00 (1.87)	2.00 (1.58)	2.06 (1.60)	1.86 (1.53)	2.00 (1.58)	3.86 (2.08)	2.93 (1.85)	2.00 (1.58)	2.00 (1.58)	3.33 (1.95)
15:00-15:10	0.20 (0.83)	2.80 (1.81)	0.13 (0.79)	2.86 (1.83)	1.60 (1.44)	1.06 (1.25)	0.00 (0.71)	2.93 (1.85)	0.00 (0.71)	2.80 (1.81)	1.20 (1.30)	2.66 (1.77)
16:00-16:10	0.00 (0.71)	2.60 (1.76)	0.00 (0.71)	0.00 (0.71)	0.13 (0.79)	0.60 (1.04)	0.00 (0.71)	2.40 (1.70)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.93 (1.19)
17:00-17:10	0.00 (0.71)	2.80 (1.81)	0.00 (0.71)	0.00 (0.71)	0.13 (0.79)	0.00 (0.71)	0.00 (0.71)	1.86 (1.53)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
18:00-18:10	0.00 (0.71)	1.80 (1.51)	0.00 (0.71)	0.00 (0.71)	0.06 (0.75)	0.00 (0.71)	0.00 (0.71)	1.20 (1.30)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
MEAN	**1.29**	**4.43**	**2.27**	**1.17**	**1.32**	**1.99**	**1.28**	**4.20**	**2.21**	**1.13**	**1.18**	**2.34**
SEM	**0.04**	**0.04**	**0.03**	**0.02**	**0.06**	**0.01**	**0.03**	**0.04**	**0.10**	**0.03**	**0.03**	**0.02**
CD@5%	**0.11**	**0.12**	**0.09**	**0.07**	**0.17**	**0.02**	**0.09**	**0.11**	**0.30**	**0.09**	**0.07**	**0.07**

Note: Ad- *Apis dorsata*, Ac- *Apis cerana*, Am- *Apis mellifera*, *T.i- Tetragonula iridipennis*. DAF- Days after flowering

Figures in the parenthesis are $\sqrt{x + 0.5}$ transformed value.

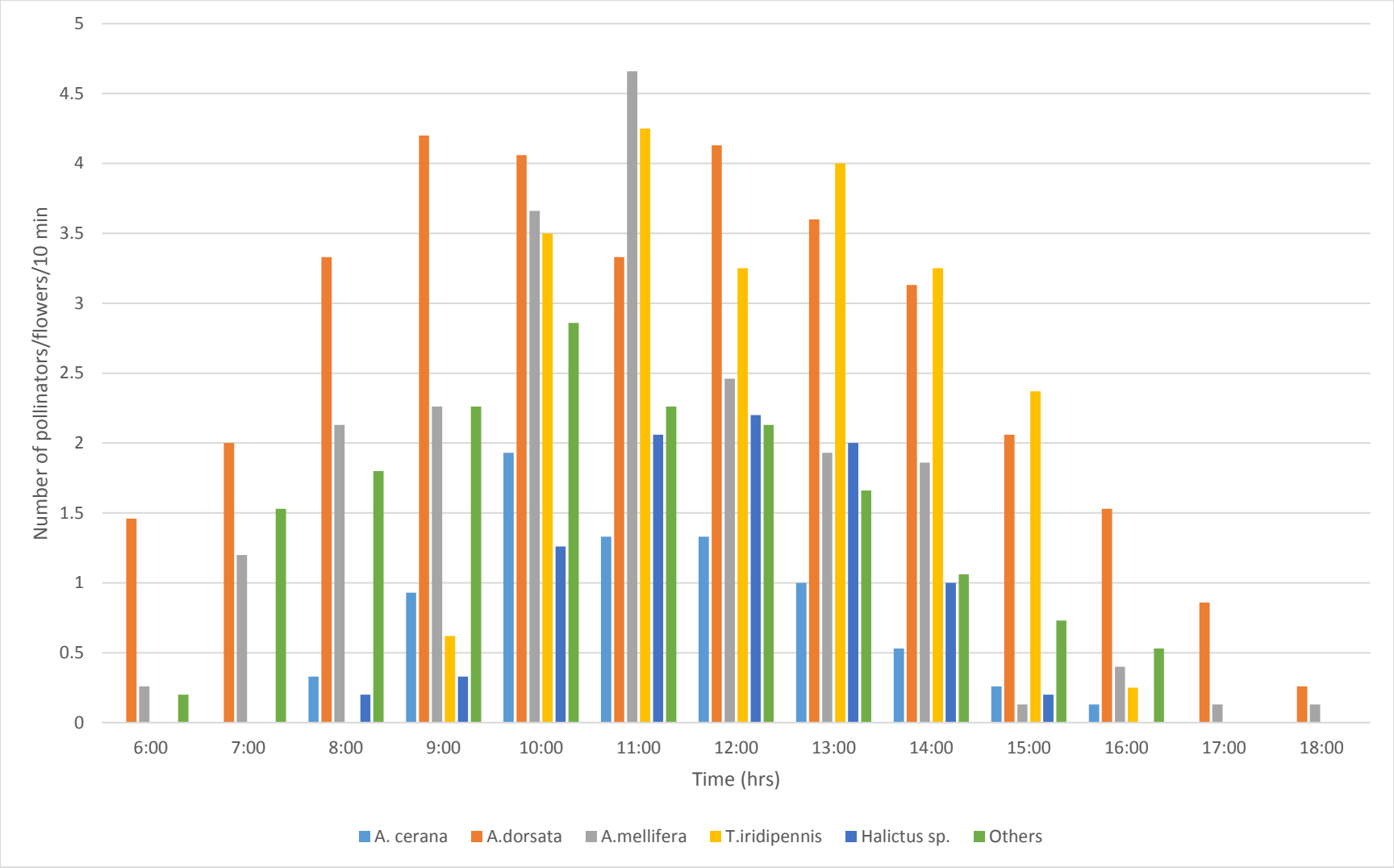

Fig. 3: Foraging activity of pollinators 15 Days after flowering

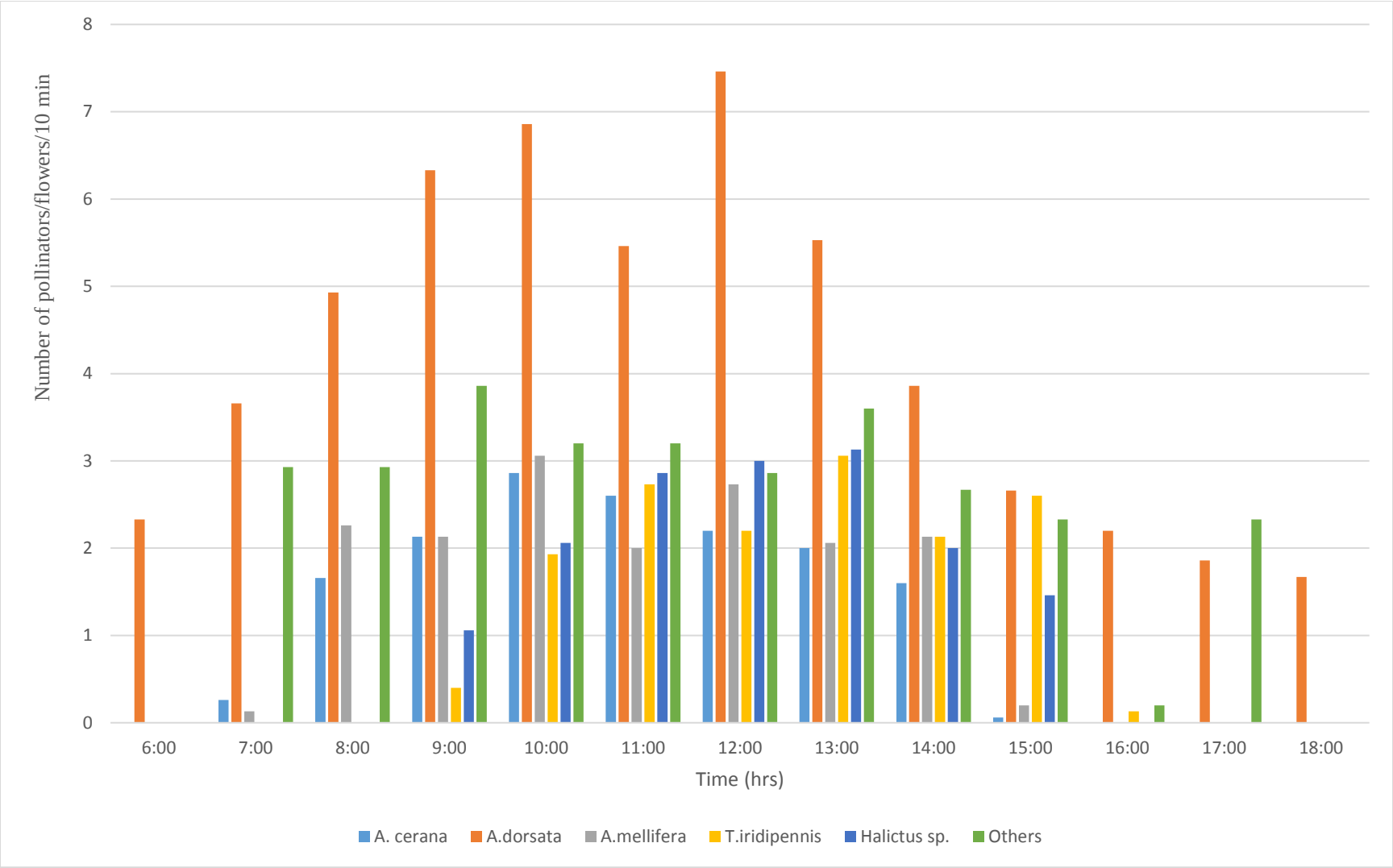

Fig. 4: Foraging activity of pollinators 30 Days after flowering

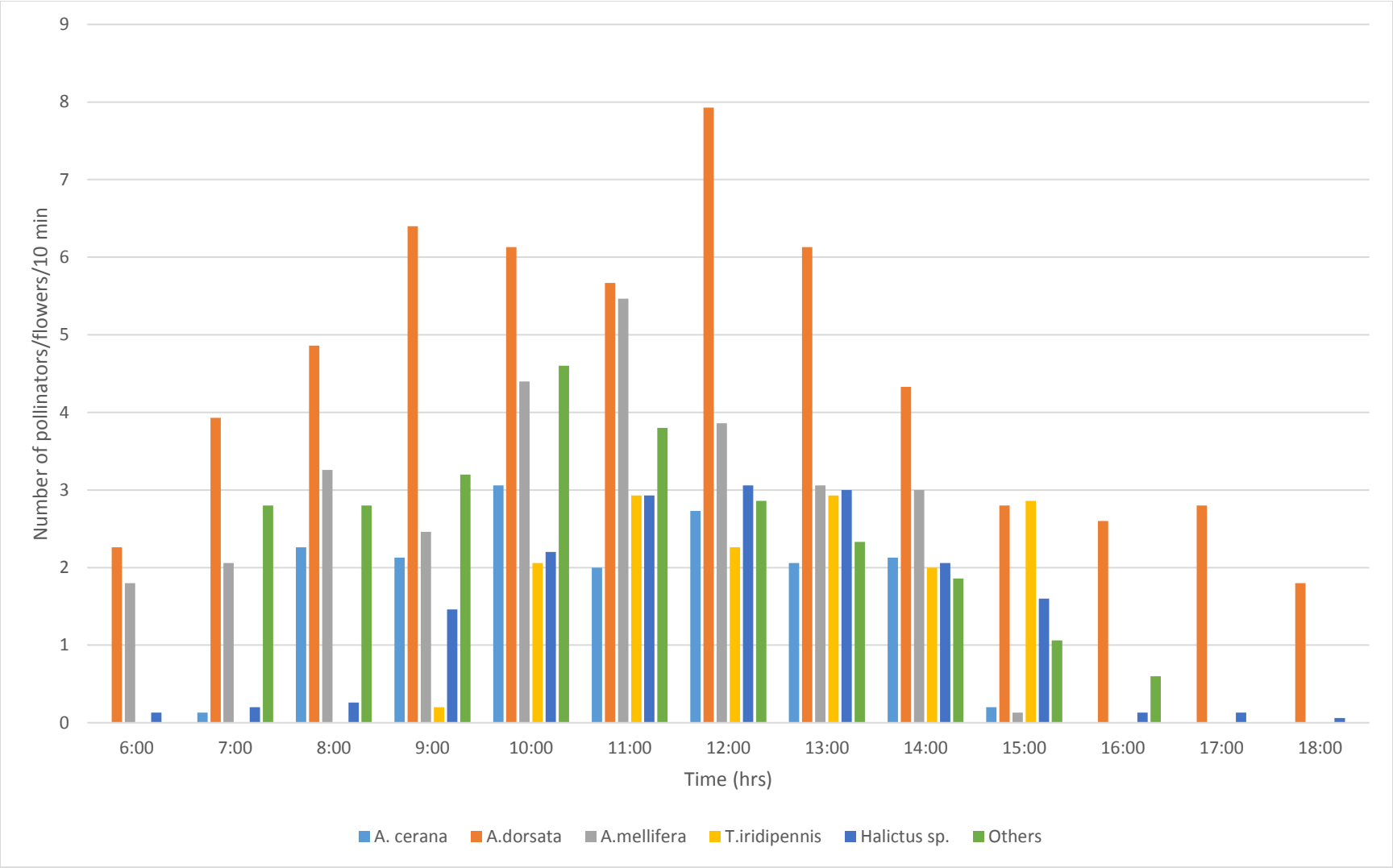

Fig. 5: Foraging activity of pollinators 45 Days after flowering

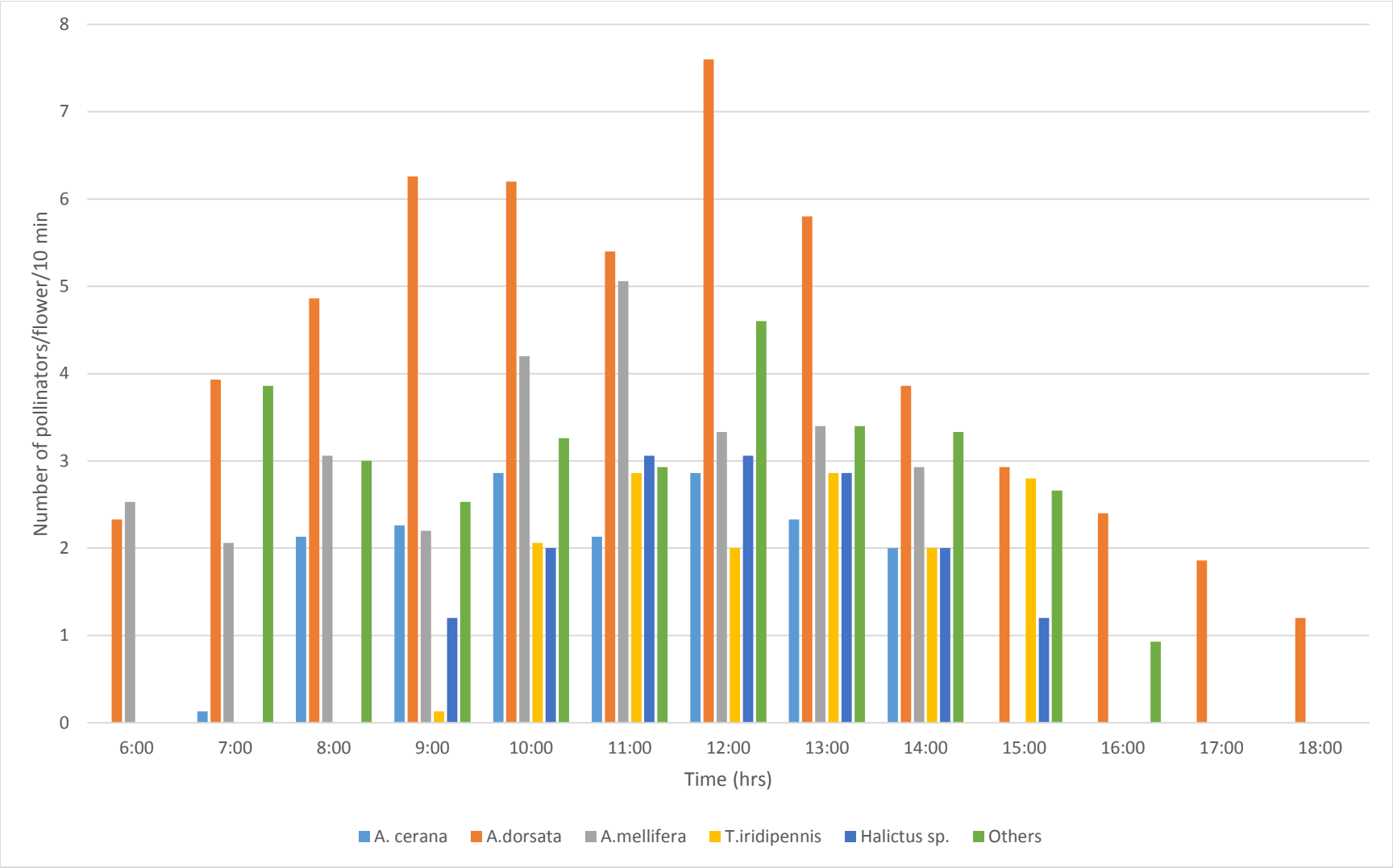

Fig. 6: Foraging activity of pollinators 60 Days after flowering

Table 10. Foraging activity of insect pollinators during 75 DAF and 90 DAF of chilli under open condition (Number of insect pollinators/flower/10 minutes)

Time (Hrs)	75 DAF						90 DAF					
	Ac	***Ad***	***Am***	***T.i***	***Halictus* sp.**	**Others**	***Ac***	***Ad***	***Am***	***T.i***	***Halictus* sp.**	**Others**
06:00-06:10	0.00 (0.71)	2.00 (1.58)	2.26 (1.66)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	2.00 (1.58)	1.93 (1.55)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
07:00-07:10	0.25 (0.86)	4.00 (2.12)	2.00 (1.58)	0.00 (0.71)	0.00 (0.71)	2.20 (1.64)	0.00 (0.71)	4.00 (2.12)	2.26 (1.66)	0.00 (0.71)	0.00 (0.71)	1.60 (1.44)
08:00-08:10	3.12 (1.90)	4.00 (2.12)	2.93 (1.85)	0.00 (0.71)	0.13 (0.79)	3.60 (2.02)	1.40 (1.37)	4.93 (2.33)	3.33 (1.95)	0.00 (0.71)	0.00 (0.71)	1.46 (1.40)
09:00-09:10	3.75 (2.06)	5.67 (2.48)	2.20 (1.64)	0.13 (0.79)	1.13 (1.27)	2.53 (1.74)	2.00 (1.58)	6.40 (2.62)	2.46 (1.72)	0.12 (0.79)	1.00 (1.22)	2.00 (1.58)
10:00-10:10	5.62 (2.47)	6.46 (2.63)	4.13 (2.15)	2.00 (1.58)	2.00 (1.58)	3.46 (1.99)	3.00 (1.87)	6.00 (2.54)	4.46 (2.22)	3.62 (2.03)	2.00 (1.58)	2.53 (1.74)
11:00-11:10	4.12 (2.15)	5.93 (2.53)	5.13 (2.37)	2.80 (1.81)	2.86 (1.83)	3.00 (1.87)	2.00 (1.58)	5.33 (2.41)	5.06 (2.35)	5.62 (2.47)	2.93 (1.85)	2.93 (1.85)
12:00-12:10	4.37 (2.20)	7.33 (2.79)	6.67 (2.67)	1.93 (1.55)	3.00 (1.87)	4.00 (2.12)	2.33 (1.68)	8.00 (2.91)	3.26 (1.94)	3.75 (2.06)	3.13 (1.90)	2.20 (1.64)
13:00-13:10	4.75 (2.29)	6.06 (2.56)	3.33 (1.95)	2.73 (1.79)	3.00 (1.87)	2.53 (1.74)	2.06 (1.60)	6.06 (2.56)	3.60 (2.02)	5.87 (2.52)	3.00 (1.87)	2.33 (1.68)
14:00-14:10	3.37 (1.96)	3.86 (2.08)	3.00 (1.87)	2.00 (1.58)	2.00 (1.58)	2.46 (1.72)	1.46 (1.40)	4.06 (2.13)	3.06 (1.88)	3.75 (2.06)	2.00 (1.58)	2.13 (1.62)
15:00-15:10	0.12 (0.79)	3.20 (1.92)	0.20 (0.83)	2.80 (1.81)	1.00 (1.22)	1.73 (1.49)	0.00 (0.71)	2.73 (1.79)	0.20 (0.83)	5.62 (2.47)	1.00 (1.22)	1.46 (1.40)
16:00-16:10	0.00 (0.71)	2.60 (1.76)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.93 (1.19)	0.00 (0.71)	2.40 (1.70)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	1.06 (1.25)
17:00-17:10	0.00 (0.71)	2.20 (1.64)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	2.26 (1.66)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.06 (0.75)
18:00-18:10	0.00 (0.71)	2.00 (1.58)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	1.93 (1.55)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
MEAN	**2.26**	**4.26**	**2.45**	**1.11**	**1.16**	**2.03**	**1.09**	**4.32**	**2.28**	**2.18**	**1.15**	**1.52**
SEM	**0.04**	**0.05**	**0.06**	**0.03**	**0.03**	**0.01**	**0.02**	**0.03**	**0.02**	**0.01**	**0.01**	**0.02**
CD@5%	**0.11**	**0.14**	**0.16**	**0.09**	**0.08**	**0.02**	**0.06**	**0.10**	**0.07**	**0.04**	**0.02**	**0.07**

Note: Ad- *Apis dorsata*, Ac- *Apis cerana*, Am- *Apis mellifera*, *T.i- Tetragonula iridipennis*. DAF- Days after flowering

Figures in the parenthesis are $\sqrt{x + 0.5}$ transformed value.

In the present study, the peak foraging activity of the insect pollinators were recorded between 09:00 AM and 11:00 AM of the day and thereafter activity was decreased during different days of flower opening. Similar observation was made by Ahmad and Aslam (2002) where they reported that the peak foraging activity was observed early in the morning from 9 to 11 AM and decreased later due to the hot weather in some vegetable crops. Macias-Macias *et al.* (2009) reported that the frequency of insect pollinator was more between 9:00 h and 12:00 h and decreased afterwards in *C. chinense*. However, slight variation in foraging activity of insect pollinator in chilli in the present study may be due to variation in climatic condition, varieties of crop and availability of pollen and nectar during different hours of the day.

4.3 Time spent (sec/flower) by honey Bees species for foraging on chilli flower

Time spent by different species of bees at different time interval vary during study period on chilli flowers.

Maximum mean time spent for pollen foraging on chilli was by *T. iridipennis* (6.20 sec/flower), followed by *A. dorsata*, *A. cerana* and *A. mellifera* (5.70, 5.10 and 5.00 sec/flower, respectively). The maximum time spent by *A. dorsata*, *A. cerana*, *T. iridipennis* and *A. mellifera* for nectar foraging was at 10:00 hrs (5.70, 5.10, 4.80 and 6.20 sec/flower, respectively) and the minimum time spent for pollen foraging was observed at 17:00 hrs (2.20, 2.70, 2.70 and 3.20 sec/flower, respectively). However, time spent for pollen foraging was in increasing trend from 06:00 hrs onwards up to 12:00 hrs and thereafter, the time spent was in decreasing trend up to end of the day. (Table 11 and fig 9)

Maximum mean time spent for nectar foraging on chilli was by *T. iridipennis* (16.20 sec/flower), followed by *A. dorsata*, *A. cerana* and *A. mellifera* (15.70, 15.10 and 15.00 sec/flower, respectively). The maximum time spent by *A. dorsata*, *A. cerana*, *T. iridipennis* and *A. mellifera* for nectar foraging was at 01:00 hrs (15.00, 15.40, 16.20 and 14.80 sec/flower, respectively) and the minimum time spent for nectar foraging was observed at 17:00 hrs (12.20, 12.70, 12.70 and 13.20 sec/flower, respectively) (Table 12 and fig 10).

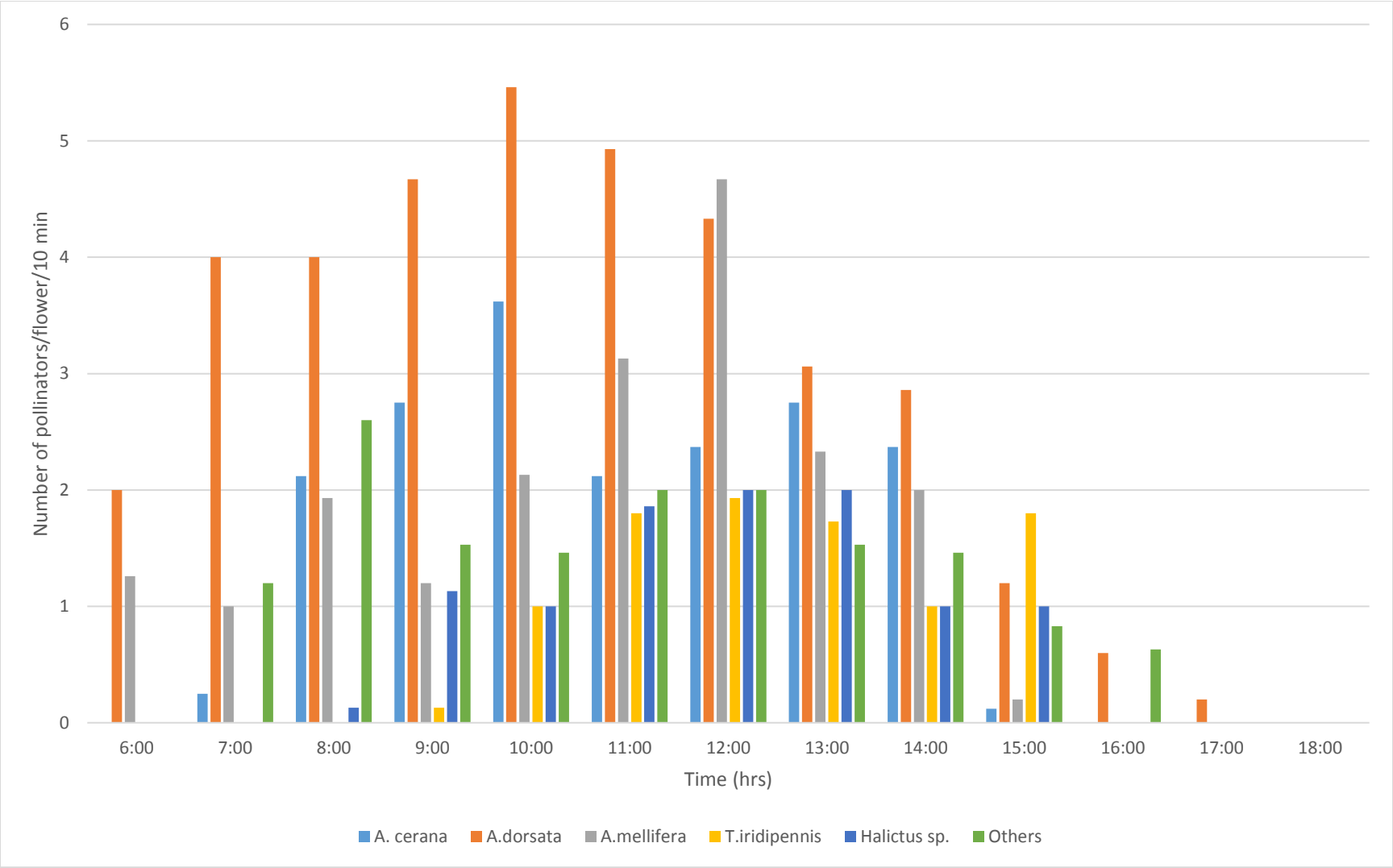

Fig. 7: Foraging activity of pollinators 75 Days after flowering

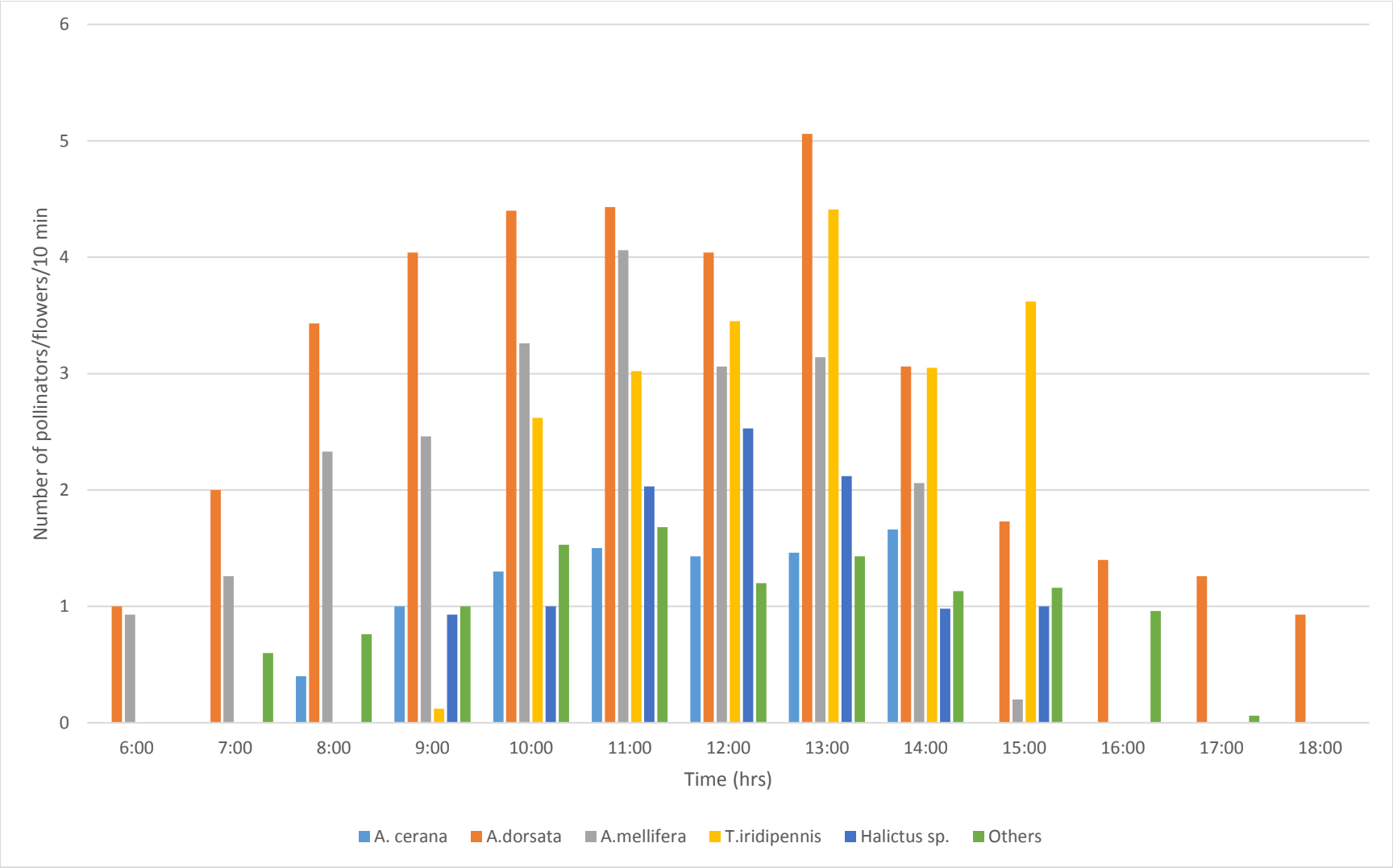

Fig. 8: Foraging activity of pollinators 90 Days after flowering

Table 11. Time spent by different honey bee species for pollen foraging

Time (Hr)	Time spent (sec/flower)			
	A.dorsata	*A.cerana*	*A.mellifera*	*T.iridipennis*
06:00	3.00 (1.87)	0.00 (0.71)	4.70 (2.28)	0.00 (0.71)
07:00	4.20 (2.17)	3.70 (2.04)	4.70 (2.28)	0.00 (0.71)
08:00	3.90 (2.09)	4.10 (2.14)	4.60 (2.26)	6.00 (2.54)
09:00	3.80 (2.07)	4.30 (2.19)	5.00 (2.34)	6.20 (2.59)
10:00	5.70 (2.49)	5.10 (2.36)	4.80 (2.30)	6.20 (2.59)
11:00	5.00 (2.34)	5.10 (2.36)	4.20 (2.17)	5.90 (2.53)
12:00	4.10 (2.14)	5.10 (2.36)	4.50 (2.24)	5.60 (2.47)
13:00	4.50 (2.23)	5.40 (2.43)	3.90 (2.09)	5.60 (2.47)
14:00	4.40 (2.21)	4.30 (2.19)	4.20 (2.17)	4.80 (2.30)
15:00	4.30 (2.19)	3.50 (2.00)	4.00 (2.12)	4.60 (2.25)
16:00	3.50 (2.00)	2.80 (1.82)	3.60 (2.02)	3.50 (2.00)
17:00	2.20 (1.64)	2.70 (1.78)	3.20 (1.92)	2.70 (1.79)
18:00	2.20 (1.64)	2.60 (1.76)	2.30 (1.67)	0.00 (0.71)
Mean±SD	**3.90±1.00**	**3.74±1.48**	**4.13±0.75**	**3.93±2.47**
SEM	**0.21**	**0.22**	**0.24**	**0.23**
CD@5%	**0.60**	**0.63**	**0.68**	**0.65**

Figures in the parenthesis are $\sqrt{x + 0.5}$ transformed value.

Table 12. Time spent by different honey bee species for nectar foraging

Time (Hr)	Time spent (sec/flower)			
	A.dorsata	*A.cerana*	*A.mellifera*	*T.iridipennis*
06:00	13.00 (1.87)	10.00 (0.71)	14.70 (2.28)	10.00 (0.71)
07:00	14.20 (2.17)	13.70 (2.04)	14.70 (2.28)	10.00(0.71)
08:00	13.90 (2.09)	14.10 (2.14)	14.60 (2.26)	16.00 (2.54)
09:00	13.80 (2.07)	14.30 (2.19)	15.00 (2.34)	16.20 (2.59)
10:00	14.10 (2.14)	15.10 (15.40)	14.50 (2.24)	15.60 (2.47)
11:00	14.50 (2.23)	15.10 (2.36)	13.90 (2.09)	15.60 (2.47)
12:00	15.70 (2.49)	15.10 (2.36)	14.20 (2.17)	16.20 (2.59)
13:00	15.00 (2.34)	15.40 (2.43)	14.80 (2.30)	15.90 (2.53)
14:00	14.40 (2.21)	14.30 (2.19)	14.20 (2.17)	14.80 (2.30)
15:00	14.30 (2.19)	13.50 (2.00)	14.00 (2.12)	14.60 (2.25)
16:00	13.50 (2.00)	12.80 (1.82)	13.60 (2.02)	13.50 (2.00)
17:00	12.20 (1.64)	12.70 (1.78)	13.20 (1.92)	12.70 (1.79)
18:00	12.20 (1.64)	12.60 (1.76)	12.30 (1.67)	10.00 (0.71)
Mean±SD	**13.90±1.00**	**13.74±1.48**	**14.13±0.75**	**3.93±2.47**
SEM	**0.31**	**0.32**	**0.34**	**0.33**
CD@5%	**0.61**	**0.64**	**0.69**	**0.64**

Figures in the parenthesis are $\sqrt{x + 0.5}$ transformed value.

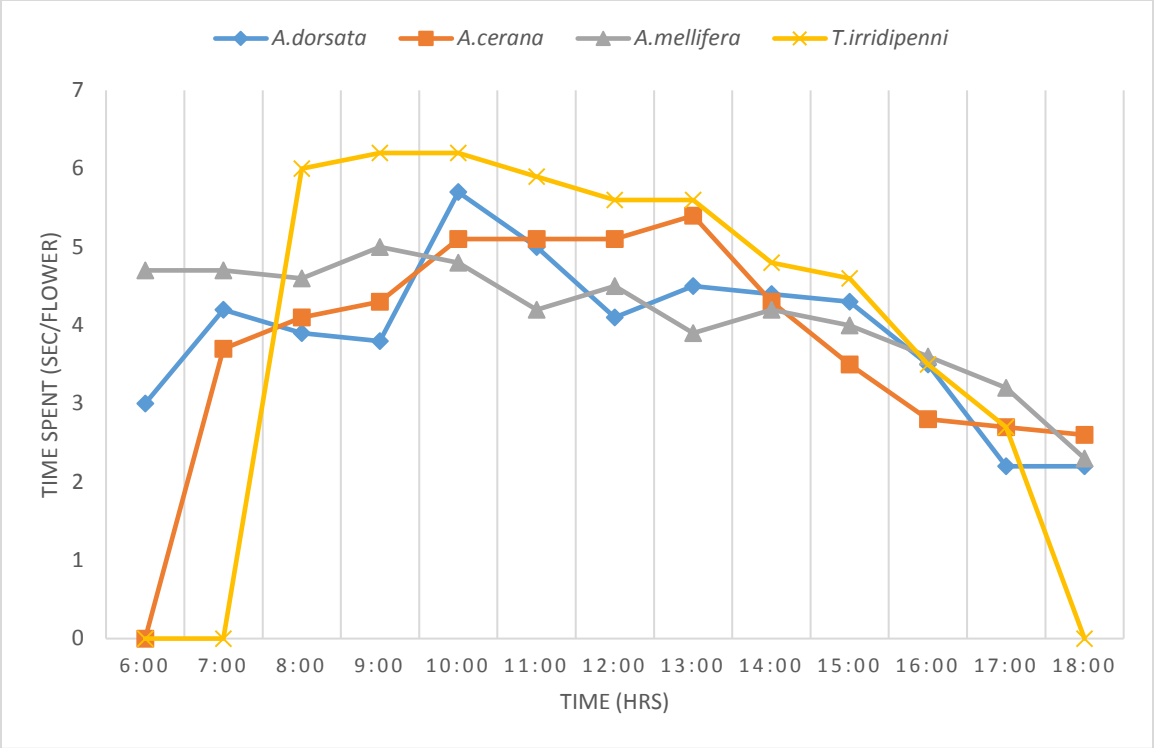

Fig. 9: Time spent for pollen collection by different species of honey bees

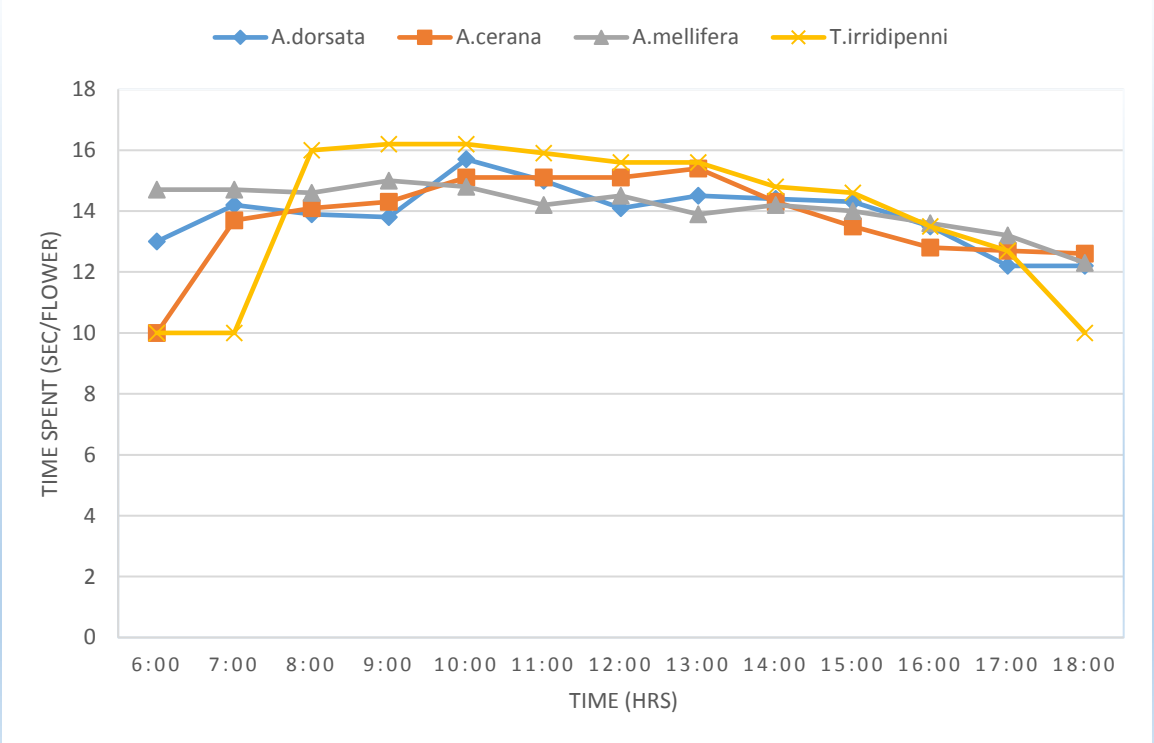

Fig. 10: Time spent for nectar collection by different species of honey bees

However, time spent for nectar foraging was in increasing trend from 06:00 hrs onwards up to 01:00 hrs and thereafter, the time spent was in decreasing trend up to end of the day.

The present study on time spent by bees on the chilli flowers are in conformity with findings of Quagliotti (1979) where he reported that pollinators such as *Tetragonisca. angustula* and *A. mellifera* spend means of 18.7 and 17.9 seconds per flower to collect pollen and 13.5 and 9.5 seconds to collect nectar. Abak *et al.* (1995) reported that time spent on flowers of eggplant was 4.8 sec per flower by stingless bees on *C. chinense*. However, slight variation may be due to availability of floral rewards and climatic conditions during study period.

4.4 Number of honey bee visits on quantitative parameters of chilli.

The abundance of *A. dorsata* and *T. irrididpennis* was maximum during the present study. Hence, the number of honey bee visits on quantitative parameters of chilli was taken on these two species. Number of bee visits to each flower significantly influenced some of the quantitative parameters such as flower drop, fruit set, fruit length, fruit weight, fruit girth, seeds per capsule and seed weight.

4.4.1 Effect of number of *T. irridipenis* bee visit

The per cent flower drop decreased significantly, when *T. irridipenis* visits increased from three bee visit per flower (62.50%) to eight bees per flower (0.00%). However, there was total flower drop, when there was zero, one and two bee visit per flower. Significantly, higher fruit set (100.00%), fruit weight (7.40g), fruit girth (1.65cm), fruit length (6.50cm), number of seeds per capsule (61.03) and seed weight (6.05g) were recorded, when the number of bee visits were maximum i.e. eight bee visit per flower. However, significantly lower fruit set (37.50%), fruit weight (4.46g), fruit girth (0.96cm), fruit length (5.50cm), number of seeds per capsule (30.00) and test weight (3.05g) were recorded, when the number of bee visits were three bee visit per flower. The shape of fruits formed by the three bee visits were small and irregular, whereas fruits

formed by four and five visits were medium. However, fruits formed by seven and eight visits per flower were long and regular in shape (Table 13).

4.4.2 Effect of number of *A. dorsata* bee visit

The per cent flower drop decreased significantly, when *A. dorsata* visits increased from two bee visit per flower (75.25%) to eight bees per flower (0.00%). However, there was total flower drop, when there was zero and one bee visit per flower. Significantly, higher fruit set (100.00%), fruit weight (7.65g), fruit girth (1.18cm), fruit length (8.95cm), number of seeds per capsule (48.70) and seed weight (5.25g) were recorded, when the number of bee visits were maximum i.e. eight bee visit per flower. However, significantly lower fruit set (24.75%), fruit weight (4.85g), fruit girth (1.00cm), fruit length (4.60cm), number of seeds per capsule (31.00) and test weight (3.30g) were recorded, when the number of bee visits were two per flower. The shape of fruits formed by the two bee visits were small and irregular, whereas fruits formed by four and five visits were medium. The fruits formed by seven and eight visits per flower were long and regular (Table 14).

In the present study minimum of six to eight bee visits of *A. dorsata* and *T. iridipennis* were necessary for qualitative improvement in chilli crop which may be due to more number of bee visits per flower resulted in proper distribution of pollen on stigma leading to better improvement fruit set, fruit weight, fruit length, fruit girth and number of seeds per capsule.

4.5 The different modes of pollination on fruit set and yield parameters.

The effect of different modes of pollination on both quantitative and qualitative parameters of chilli showed significant variation.

4.5.1 Quantitative parameters

Quantitative parameters such as flower drop, fruit set, fruit weight, fruit length, fruit girth, number of seed per capsule and weight of seeds differed significantly among different modes of pollination in chilli (Table 15).

Table 13. Effect of number of *Tetragonula iridipennis* visits on quantitative parameters of chilli

No of bee visits	Flower drop (%)	Fruit set (%)	Fruit weight (g)	Fruit girth (cm)	Fruit length (cm)	No of seeds / capsule	Seed weight (g)
0	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
1	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
2	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
3	62.50 (7.94)	37.50 (6.16)	4.46 (2.23)	0.96 (1.21)	5.50 (2.45)	30.00 (5.52)	3.05 (1.88)
4	49.25 7.05)	50.75 (7.16)	5.15 (2.38)	0.98 (1.22)	5.65 (2.48)	42.14 (6.53)	3.85 (2.09)
5	38.50 (6.24)	61.50 (7.87)	6.23 (2.59)	1.20 (1.30)	5.40 (2.43)	53.37 (7.34)	4.52 (2.24)
6	22.50 (4.80)	77.50 (8.83)	6.50 (2.65)	1.45 (1.40)	5.49 (2.45)	55.69 (7.50)	5.08 (2.36)
7	9.00 (3.08)	91.00 (9.57)	6.95 (2.73)	1.34 (1.36)	6.30 (2.61)	59.75 (7.76)	5.68 (2.49)
8	0.00 (0.71)	100.00 (10.02)	7.40 (2.81)	1.65 (1.47)	6.50 (2.65)	61.03 (7.84)	6.05 (2.56)
Mean	**53.53**	**46.47**	**4.08**	**0.84**	**3.87**	**33.55**	**3.14**
SEM±	**0.8**	**0.48**	**0.04**	**0.004**	**0.04**	**0.01**	**0.01**
CD@5%	**1.32**	**1.42**	**0.14**	**0.01**	**0.13**	**0.04**	**0.02**

Figures in the parenthesis are $\sqrt{x + 0.5}$ transformed value.

Table 14. Effect of number of *Apis dorsata* visits on quantitative parameters of chilli

No of bee visits	Flower drop (%)	Fruit set (%)	Fruit weight (g)	Fruit girth (cm)	Fruit length (cm)	No of seeds / capsule	Seed weight (g)
0	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
1	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
2	75.25 (8.70)	24.75 (5.02)	4.85 (2.31)	1.00 (1.22)	4.60 (2.26)	31.00 (5.61)	3.30 (1.95)
3	64.50 (8.06)	35.50 (6.00)	4.96 (2.34)	1.06 (1.25)	5.45 (2.44)	38.00 (6.20)	3.76 (2.06)
4	56.25 (7.53)	43.75 (6.65)	5.45 (2.44)	1.08 (1.26)	6.67 (2.68)	42.24 (6.54)	4.05 (2.13)
5	49.75 (7.09)	50.25 (7.12)	6.23 (2.59)	1.10 (1.26)	7.70 (2.86)	46.79 (6.88)	4.55 (2.25)
6	32.50 (5.74)	67.50 (8.25)	6.40 (2.63)	1.12 (1.27)	8.45 (2.99)	45.57 (6.79)	4.83 (2.31)
7	0.50 (1.00)	99.50 (10.00)	7.45 (2.82)	1.14 (1.28)	8.67 (3.03)	43.50 (6.63)	5.01 (2.35)
8	0.00 (0.71)	100.00 (10.02)	7.65 (2.85)	1.18 (1.30)	8.95 (3.07)	48.70 (7.01)	5.25 (2.40)
Mean	**53.19**	**46.81**	**4.78**	**0.85**	**5.61**	**32.87**	**3.42**
SEM	**0.89**	**0.53**	**0.04**	**0.004**	**0.04**	**0.01**	**0.01**
CD@5%	**1.45**	**1.64**	**0.12**	**0.01**	**0.11**	**0.04**	**0.02**

Figures in the parenthesis are $\sqrt{x + 0.5}$ transformed value.

Table 15. Effect of different modes of pollination on the quantitative parameters

Pollination type	Flower drop (%)	Fruit set (%)	Fruit weight (g)	Fruit length (cm)	Fruit girth (cm)	No. of sound seeds/fruit	Seed weight (g)
Open pollination	15.45^{g}	84.55^{a}	8.44^{a}	8.56^{a}	1.60^{a}	55.68^{c}	5.45^{a}
***A. dorsata* pollination**	32.56^{b}	67.44^{f}	6.89^{de}	6.90^{d}	1.12^{d}	52.66^{e}	4.29^{e}
***A.cerana* pollination**	29.12^{c}	70.88^{e}	6.75e	7.56^{c}	1.43^{c}	54.32^{d}	4.45^{d}
***A.mellifera* pollination**	27.75^{d}	72.25^{d}	7.24^{c}	8.06^{b}	1.56^{b}	59.32^{b}	5.01^{c}
***T. iridipennis* pollination**	18.65^{f}	81.35^{b}	5.75^{fg}	4.50^{e}	0.98^{f}	62.72^{a}	4.06^{f}
Hand pollination	19.13^{e}	80.87^{c}	7.34^{bc}	5.65^{f}	1.04^{e}	45.32^{f}	5.05^{b}
Self-pollination	35.75^{a}	64.25g	5.60^{g}	3.50^{g}	0.90^{g}	30.63^{g}	3.89^{g}
Mean	25.49	74.51	6.86	6.39	1.23	51.52	4.60
SEM±	0.12	0.14	0.04	0.04	0.004	0.58	0.01
CD±	0.40	0.40	0.16	0.18	0.01	1.68	0.02

Mean values followed by the same alphabet in the columns do not differ significantly by DMRT at 5% level

4.5.1.1 Flower drop

Significantly higher flower drop was recorded in control treatment (35.75%) and minimum in open pollination (15.45%) which was followed by hand pollination (19.13%), *A. mellifera* (27.75%), *A. cerana* (29.12%), *T. iridipennis* (18.65%) and *A. dorsata* (32.56%) pollination treatment.

4.5.1.2 Fruit set

The maximum fruit set was recorded in open pollination (84.55%), followed by *T. iridipennis* (81.35%), hand pollination (80.87%), *A. cerana* (70.88%), *A. mellifera* (72.75%), *A. dorsata* (67.44%) and minimum in control treatment (64.25%).

4.5.1.3 Fruit weight

Significantly maximum fruit weight was recorded in open pollination treatment (8.44g) and minimum in self-pollination (5.60g) which was followed by *T. iridipennis* (5.75g), *A. cerana* (6.75g), *A. dorsata* (6.89g), *A. mellifera* (7.24g) and hand pollination (7.34g).

4.5.1.4 Fruit length

Significantly maximum fruit length was recorded in open pollination treatment (8.56cm) and minimum in self-pollination (3.50cm) which was followed by *T. iridipennis* (4.50cm), hand pollination (5.65cm), *A. cerana* (7.56cm), *A. dorsata* (6.90cm) and *A. mellifera* (8.06cm) pollination treatment.

4.5.1.5 Fruit girth

Significantly maximum fruit length was recorded in open pollination treatment (1.60cm) and minimum in self-pollination (0.90cm) which was followed by *T. iridipennis* (0.98cm), hand pollination (1.04cm), *A. dorsata* (1.12cm) *A. cerana* (1.43cm), and *A. mellifera* (1.56cm) pollination treatment.

4.5.1.6 Number of seeds/capsule

Significantly maximum number of seeds per capsule was recorded in *T. iridipennis* pollination (62.72) and minimum in self-pollination (30.63) which was followed by hand pollination (45.32), *A. mellifera* (59.32), *A. cerana* (54.32), open pollination treatment (55.68) and *A. dorsata* (52.66) pollination treatment.

4.5.1.7 Seed weight

Significantly maximum seed weight was recorded in open pollination (5.45g), followed by *A. cerana* (4.45g), hand pollination (5.05g), *A. mellifera* (5.01g), *A. dorsata* pollination (4.29g), *T. iridipennis* (4.06g) and minimum in self-pollination (3.89g).

4.5.2 Qualitative parameters

Qualitative parameters such as moisture content, total soluble solids, germination per cent and seedling vigour significantly among different modes of pollination in chilli (Table 16).

4.5.2.1 Moisture content

The maximum moisture content was recorded in open pollinated plot (84.50%), followed by *A. mellifera* (83.65%), self-pollination (82.50%), *T. iridipennis* (81.50%), *A. cerana* (81.50), hand pollination (80.50) and *A. dorsata* pollination (79.90%).

4.5.2.2 Total soluble solids

There was no variation in total soluble sugar content among different modes of pollination. However, the TSS recorded in all the modes of pollination was 3-3.20 per cent.

4.5.2.3 Germination per cent

The germination percentage was maximum in open pollination (60%), followed by the *T. iridipennis* (48.84%), *A. dorsata* (55.02%), *A. cerana* (44.01%), *A. mellifera* (50.05%), hand pollination (49.01%) and self -pollination (41.06%).

Table 16. Effect of different modes of pollination on the qualitative parameters of chilli

Pollination type	Moisture (%)	TSS (%)	Germination (%)	Seedling vigour
Open pollination	84.50[a]	3.20	60.00[a]	520.01 [a]
***A. dorsata* pollination**	79.90[g]	3.20	55.02 [a]	453.64 [c]
***A. cerana* pollination**	81.50[de]	3.20	44.01 [a]	486.43 [b]
***A. mellifera* pollination**	83.65[b]	3.20	50.05 [a]	424.79 [e]
***T. iridipennis* pollination**	81.50[e]	3.20	48.84 [a]	389.05 [g]
Hand pollination	80.50[fg]	3.01	49.01 [a]	415.78 [f]
Self-pollination	82.50[c]	3.20	41.06 [b]	426.89 [d]
Mean	82.00	3.28	49.71	445.23
SEM±	0.17	3.17	4.32	0.04
CD±	0.46	NS	12.06	0.11

Mean values followed by the same alphabet in the columns do not differ significantly by DMRT at 5% level

4.5.2.4 Seedling vigour index

The seedling vigour index was maximum in open pollination (520.01), *T. iridipennis* (389.05), *A. dorsata* (453.64), *A. cerana* (486.43), *A. mellifera* (424.79), hand pollination (415.78) and self -pollination (426.89).

Erwin (1932) reported that 71% of crossed flowers developed into fruits, whereas only 46% of selfed flowers did so. Pollination by *T. leaviceps* and *T. Minangkabau* increased number and per cent fruit sets (12.32 and 9.66%), number of seeds (56.36 and 45.91%), number of fruits (29.31 and 25.06), fruit weight per plant (66.46 and 49.75%) and yields ha-1 54.26% and 40.83% compared to pollination by wind. However, fruit length and diameter did not get affected. Cruz *et al.* (2004) also reported increase in number of fruits (51%) number of seeds (85%) and fruit weight (69%) in sweet pepper because of pollination by *Melipona subnitida* compared to pollination by wind. Jarlan *et al.* (1997) reported that increase of yield of *Capsicum* up to 19.3% due to pollination by stingless bees. Kwon and Saeed (2003) found that increase in fruit weight (27.2%) and number of seeds (47.8%) in *Capsicum* was due to pollination by bees. Suryani (1999) reported that using *Trigona minangkabau* as pollinator on chili pepper plant increased fruit set by 65% compared to pollination by other insects (59%) and wind (56%). Carr and Davidar, (2015) reported that fruit set per cent in chilli in open pollination was ranged from 72% to 86%, 50% in self-pollination 50% and 65% to 86% in cross pollination. However, slight variation in both qualitative and quantitative parameters in the present study with earlier studies made by researchers may be due to vary in climatic condition of the location, soil type and even pollinators abundance on chilli flowers.

V SUMMARY

The floral biology, insect pollinators and their abundance, forging behaviour, effect of number of bee visits and impact of different modes of pollination on quantitative and qualitative parameters of chilli, *Capsicum annum* L. were studied at the University of Agricultural Sciences, GKVK, Bengaluru and the salient findings have been summarized here under.

Chilli was an annual herbaceous plant grow upright about 1-1.5 meter. Flowers were produced at axil of the first branching node in clusters of 2-3. The flower opened at 06:00 h and remained open for 3days. Anthesis was maximum between 06:00h to 07:00 and pollen dehiscence initiated at 07:00 h onwards. Chilli flowers were good source of pollen and poor source of nectar yielding 1- 1.5 mg pollen and 0.25 µl of nectar per flower.

Chilli flowers were visited by thirteen species of insect pollinators during flowering period of chilli. Among them, ten species belonged to order Hymenoptera, one to order Lepidoptera and two to Diptera. Hymenopterans consisted of ten species, of which seven species from family Apidae (*Apis dorsata* Fab., *Apis florea*. Fab, *Apis cerana* Fab., *Apis mellifera* Fab, *Tetragonula iridipennis* Smith, *Amegilla zonata* Linn. *and Ceratina binghami* Cokerell), two species from halictidae (*Halictus ligatus* Say and *Nomia irridisence* Smith), one from Vespidae (*Vespula vulgaris* Linn.). Dipteran consisted of one species each from Sarcophagidae (*Sarcophaga sp.*) and Syrphidae (*Syrphus* sp.). Lepidoptera consisted of one species from Pieridae (*Belenois aurota*).

Among the pollinators visited chilli, the abundance of honey bee species constituted 64.01 per cent. Among the honey bee species, the per cent relative abundance of *A. dorsata* was maximum (20.45%), followed by *A. mellifera* (17.58%), *T. iridipennis* (15.05%) and *A. cerana* (10.93%), whereas the *H. ligatus* constituted 16.58 per cent of the total pollinators visited the flowers of chilli. Similarly, the relative abundance of other pollinators was 19.46 percent.

Maximum foraging activity of *A. cerana*, *A. dorsata*, *A. mellifera* and *Tetragonula iridipennis* were recorded at 10:00 and 12:00 h (2.93 and 2.33, 7.06 and 7.13, 4.66 and 3.46 and 4.50 and 4.50 and 5.25 bees/plant/ 10 min, respectively) during fifteen days after flowering. Similarly, the number of *A. cerana*, *A. dorsata*, *A. mellifera* and *Tetragonula iridipennis* were maximum at 10:00 to 12:00h (2.86 and 2.20,6.86 and 7.46, 3.06 and 2.73 and 1.93 and 2.20 bees/plant/10 min, respectively) during thirty days after flowering. Maximum number of *A. cerana*, *A. dorsata*, *A. mellifera* and *T. iridipennis* were recorded at 10:00 and 12:00 h (3.06 and 2.73, 6.13 and 7.93, 4.40 and 3.86 and 2.06 and 2.26 bees/plant/ 10 min, respectively), during forty-five days after flowering. Maximum number of *A. cerana*, *A. dorsata*, *A. mellifera* and *T. iridipennis* were recorded at 10:00 and 12:00 h (2.86 and 2.86, 6.20 and 7.60, 4.20 and 3.30 and 2.06 and 2.00 bees/plant/ 10 min, respectively) during sixty days after flowering. Maximum number of *A. cerana*, *A. dorsata*, *A. mellifera* and *T. iridipennis* were recorded at 10:00 and 12:00 h (5.62 and 4.37, 6.46 and 7.30, 4.13 and 6.67 and 2.00 and 1.93 bees/plant/ 10 min, respectively) during seventy-five days after flowering. Maximum number of *A. cerana*, *A. dorsata*, *A. mellifera* and *T. iridipennis* were recorded at 10:00 and 12:00 h (3.00 and 2.33, 6.00 and 8.00, 4.46 and 3.26 and 3.62 and 3.75 bees/plant/ 10 min, respectively) during ninety days after flowering. However, the maximum foraging activity of insect pollinator were observed between 09:00 to 11:00 h of day irrespective of number of days after flowering. However, the maximum foraging activity of insect pollinators were observed between 9 to 11 h of day irrespective of number of days after flowering of chilli crop.

There was a significant variation in time spent by honey bee species for foraging on chilli flower in different hours of the day during study period. The maximum time spent by *Apis dorsata, Apis cerana, Apis mellifera and T. iridipennis* on chilli flower for pollen and nectar foraging was at 10:00 h and 13:00 h (5.70 and 15.00, 5.10 and 15.40, 4.80 and 14.80 and 6.20 and 15.90 sec/flower respectively).

The maximum of eight bee visits of *A. dorsata* and *T. iridipennis* per flower was found to be better in quantitative improvement of chilli crop with respect to fruit set (100.00% and 75.25%), fruit weight (7.40g and 7.65g), fruit girth (1.65cm and 1.18cm), fruit length (6.50cm and 8.95cm), number of seeds per capsule (61.03 and 48.70) and seed weight (3.05g and 3.30g).

The effect of honey bee pollination on quantitative parameters such as flower drop, fruit set, fruit weight, fruit length, fruit girth, number of seeds per capsule and seed weight were maximum in open pollination (15.45%, 84.55%, 8.44g, 8.56cm, 1.60cm, 55.68 and 5.45g) compared to self-pollination and honey bee pollination treatments. Among honey bee pollination treatments, fruit set and number of seeds per capsule was maximum in *T. iridipennis* (81.35% and 62.72) and fruit weight and length (7.34g) was maximum in hand pollination treatment.

The qualitative parameters such as moisture per cent, germination per cent and seedling vigour (84.50%, 60.00% and 520.01) were maximum in open pollination compared to self-pollination and honey bee pollination treatments. Among honey bee pollination treatments, maximum germination per cent was recorded in *A. mellifera* pollination and seedling vigour index in case of *A. cerana* pollination. However, the total soluble sugar was 3.20 per in all the modes of pollination except in hand pollination (3.01).

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