POLLINATION POTENTIAL OF *APIS* SPECIES ON GUAVA AND LITCHI

THESIS

By

AKASH
(A-2018-30-027)

Submitted to

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CERTIFICATE – I

This is to certify that the thesis entitled, **“Pollination potential of *Apis* species on guava and litchi”** submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Agriculture)** in the discipline of **Entomology** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Akash (Admission No. A-2018-30-027)** son of **Mr. Lalit Thapa** and **Mrs. Rita** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place : Palampur
Dated : 9th November, 2020

Dr. Surender Kumar Sharma
Major Advisor

CERTIFICATE- II

This is to certify that the thesis entitled, **"Pollination potential of *Apis* species on guava and litchi"** submitted by **Akash (Admission No. A-2018-30-027)** son of **Mr. Lalit Thapa** to the CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture)** in the discipline of **Entomology** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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Place : Palampur
Dated : 9th November, 2020 ***(Akash)***

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LIST OF ABBREVIATIONS USED

Sr. No.	Abbreviations	Meaning
1.	%	Per cent
2.	/	Per
3.	sec.	Seconds
4.	CD	Critical Difference
5.	et al.	Et alii (and other)
6.	Fig.	Figure
7.	*i.e.*	Id est (that is)
8.	MT	Metric tones
9.	spp.	Species (many)
10.	*viz.,*	Vi delicet (namely)
11.	&	And
12.	mg	Milligram
13.	*etc.*	Et cetera
14.	m^2	Square meter
15.	€	Euro
16.	µl	Microlitre
17.	P=0.05	At 5 per cent level of probability
18.	NS	Non-significant
19.	ha	Hectare (s)
20.	min.	Minute (s)
21.	cm	Centimeter
22.	$	Dollar
23.	P.E.I.	Pollination efficiency index
24.	*e.g.*	Exempli gratia (for example)
25.	hrs.	Hours
26.	C.V.	Coefficient of variation
27.	var.	Variety
28.	subsp.	Subspecies
29.	sp.	Species (single)
30.	PM	Post Meridiem
31.	^{o} C	Degree Celsius
32.	mm	Millimeter
33.	SD	Standard deviation
34.	AM	Ante Meridiem
35.	Amsl	Above mean sea level

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ABSTRACT

Guava and litchi are the two commercially important fruit crops grown in Shivalik Hills of Himachal Pradesh. Owing to their pollination, the present study holds potential for improving their reproductive success by utilizing most suited honeybee pollinators. The prime aim of the present investigation was to study the foraging traits of honeybees in guava and litchi ecosystems, ensuring effective pollination services. Healthy and bearing trees of guava (var. Allahabad Safeda) and litchi (var. Culcuttia) were chosen as experimental material for study. Abundance and foraging traits; foraging rate, foraging speed, foraging mode and pollination efficiency index were determined. Visitor insects were observed in litchi and guava ecosystems of six different locations during morning and afternoon hours. Data were recorded by selecting four branches in different directions of the tree. Honeybees followed by syrphids were the predominant visitors of litchi both during early and peak blooming period. Out of the three predominant honeybee species, *Apis cerana* was most frequent (10.19 flowers/min.) in the morning hours and *Apis mellifera* visited maximum flowers (10.04 flowers/min.) during afternoon hours. Foraging speed as time spent per flower was recorded maximum for *Apis dorsata* (7.55 sec.) during morning and *A. cerana* (7.34 sec.) in afternoon hours. Foraging mode indicated the maximum top foragers of *A. mellifera.* Maximum number of loose pollen grains among *Apis* pollinators on body and hind legs was carried by *A. dorsata. A. mellifera* with highest pollination efficiency index was found as the most efficient pollinator in litchi ecosystem. In guava ecosystem, honeybees were again abundant during the early bloom while *A. cerana* was the most prevalent during peak bloom. Maximum foraging rate, both in morning and afternoon hours was observed for *A. cerana*. *A. mellifera* and *A. cerana* had the maximum foraging speeds *i.e.* 6.83 seconds and 9.56 seconds during morning and afternoon hours, respectively. Foraging mode of honeybees revealed that in guava crop, maximum top foragers were of *A. dorsata* and the least of *A. cerana.* Maximum number of loose pollen grains among honeybees on body and hind legs was recovered from *A. dorsata.* The pollination efficiency index of *A. cerana* in guava was highest as 6.54, hence, represented the most efficient pollinator in the surveyed locations of Shivalik Hills.

(Akash)	**Dr. Surender Kumar Sharma**
Student	**Major Advisor**
Date: 9th November, 2020	**Date: 9th November, 2020**

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1. INTRODUCTION

Insects play a major role in boosting agricultural production by significantly increasing the yields of crops, vegetables, fruits and seeds through pollination (Verma and Chauhan 1985; Abrol 1993; Pashte and Kulkarni 2015). Insects render essential ecosystem services in many pollination dependent crops and natural plant populations contributing up to 80 per cent. Among insects, honeybees are, however, critically important for crop pollination worldwide (Levin and Waller 1989; Watanabe 1994; Thapa 2006; Klein et al. 2007). Pollinators affect 35 per cent of the world's production, increasing outputs of 87 of leading crops worldwide. Approximately three fourth of the crops cultivated worldwide depend to some degree on pollinators to produce seeds, fruits and vegetables (Free 1993; Roubik 1995; Delaplane and Mayer 2000). Pollinators are also helpful in improving the quality of crops (Morandin and Winsten 2006; Klatt et al. 2014).

Effective management for improving pollination can influence farmer's income through increased yield and yield stability of many food crops (Klein et al. 2007; Garibaldi et al. 2011). Planned pollination adequately determines fruit and seed quality as well as nutrient content (Eilers et al. 2011; Brittain et al. 2014).

In recent years, an increased stress has been given to enhance the agriculture production in India. Conventional techniques that ensure a healthy growth of crop plants, work only up to a limit, at some stage productivity even become stagnant or decline with additional inputs (Verma 1990). The little harnessed method of increasing crop productivity is through managed pollination of crops using beneficial insects like honeybees which in the process of search of food, perform this useful service to farmers (Partap and Partap 1997).The widespread use of honeybees as the prime managed pollinator for temperate fruit crops, their contribution to fruit production, fruit quality and farmer's profits remain poorly known (Garratt et al. 2014; Marini et al. 2015). Understanding the dependence on honeybee pollination for yield and fruit quality is critical to develop managing strategies that enhance pollination and reduce temporal variability in production and farmers' profits (Garratt et al. 2014).

The pollinator's diversity is dependent on the availability of floral resources (Gathmann et al. 1994). Insect pollinators play a crucial role in affecting optimum pollination of many crops and contributing to both increased productivity and quality. The important insect pollinators which coexist with honeybees include: solitary bees (*Xylocopa* spp., *Andrena* spp. and *Halictus* spp.), bumble bees, stingless bees (*Trigona* spp., *Melipona* spp.) and dipteran flies (*Syrphus* spp., *Bombus* spp.). Insects mainly belonging to the orders of Hymenoptera, Lepidoptera, Coleoptera, Diptera, Hemiptera *etc.* are the most common and dominant pollinators in various regions.

Over 84 per cent of crops and 78 per cent of temperate wildflowers need biotic pollination and over 10 per cent of the total economic output valued €22 billion in 2005 are the estimated losses per year due to lack of insect pollination in Europe (Potts 2015). In another estimate, a total economic value of crop pollination worldwide has been estimated at €156 billion annually (Gallai et al. 2009). About 73 per cent of the cultivated crops are pollinated by bees, 19 per cent by flies, 6.5 per cent by bats, 5 per cent by wasps, 5 per cent by beetles, 4 per cent by birds, and 4 per cent by butterflies & moths (Abrol 2009).

Hymenopterans, especially honeybees, bumble bees, solitary bees and wasps are the most important insect pollinators because of their high energy requirements and tendency for collecting provisions for their brood in the form of pollen and nectar (Kozin 1972; McGregor 1976). Among hymenopterans, honeybees are considered as the most efficient pollinators of cultivated crops because of their easily hive management, floral fidelity, potential for long working hours, presence of hairy body, corbicula on hind legs, maintainability of high population, micromanipulations of flowers and adaptability to varied climatic conditions (Crane 1990;Verma 1997).

The pollinators have undergone severe and widespread declines all over the world due to loss and fragmentation of habitat, pesticides, loss of floral resources, pests and diseases, alien invasive species and climate change. To conserve pollinator diversity and effects of pollinator extinction the reproduction of rare plants and their populations are essential (Beismeijer et al. 2006; Bond 1994).

In India, out of a total cropped area of about 160 million hectares, 55 million hectares are under insect-pollinated crops requiring cross pollination (Gupta and

Gupta 1997). Besides honeybees, in recent years much attention is also being given to commercial utilization of other hymenopterans and dipterans like bumble bees, solitary bees, wasps, drone fly, muscids, syrphids *etc.* as important pollinators in developed countries. Some species of bumble bees are commercially reared and used for pollination of lucerne and other crops that are not pollinated effectively by honeybees. Similarly, crops like cashew, mango, high bush blueberry, cranberry, squash, cacao and cardamom having a combined average value of $ 1.2 billion are pollinated by wild insects. But the importance of this large worldwide pollinator group (20,000 species) remains limited due to year to year variation in their population densities (Gupta and Gupta 1997).

Since litchi and guava are two important fruit crops of our state especially in Kangra district. Litchi is being grown in the state on an area of about 3.303 thousand ha with fruit production of 3.292 thousand MT while guava is being grown on 0.772 thousand ha and produces 0.521 thousand MT (Anonymous 2018). Various insect fauna visit their blooms but honeybees have been regarded as the most efficient pollinators of guava to increase its fruit set and quality of fruit (Rajagopal and Eswarappa 2005). In commercial litchi production insects play a major role (Menzel and Waite 2005) but honeybees especially *Apis mellifera* has been amongst the most efficient pollinators (Kumar 2014).

Himachal Pradesh has a rich heritage of resources and numerous insect species in different agro-climatic zones. Measuring pollinator performance has become increasingly important with emerging needs for risk assessment in conservation and sustainable agriculture and it requires multi-year and multi-site comparison studies. A number of alternate terms for pollinator performance such as effectiveness, efficiency, efficacy, *etc*. have been used (Potts et al. 2001). Keeping in view the importance of pollinators it is imperative to assess their relative abundance, foraging attributes and pollination characteristics to know their potential in different crops. The present proposal aims to identify and assess these potentialities of visiting insect fauna in litchi and guava trees.

Objectives of study

(1) To study relative abundance and foraging attributes of insect pollinators, and

(2) To work out pollination efficiency on guava and litchi

2. REVIEW OF LITERATURE

Pollination is an important process, needed for higher yields of agricultural and horticultural crops (Free 1993). The process of pollination encompasses all events from the maturation of the pollen in the anther to the division of the fertilized zygote and the successful completion of the sequence resulting into optimum yield. Failure at any stage can bring about crop yield reduction or total loss (Uppal et al. 1997). The importance of pollination to the yield of most crops grown in temperate climates is known partially but there is relatively little information about pollination of tropical crops. There are several measures, both direct and indirect for pollination studies which differ greatly in their dependability as indices of pollination. To record yield and fruit counts is not a representative of impact of pollination as it is influenced by plant maternal characters. Similarly, it is overestimated in parthenocarpic crops. A direct method to quantify pollination is to count the pollen grains placed on the stigma. This can be accomplished by various methods depending largely on the flower size and morphology of the stigma and pollen. Litchi flowers are generally recognized as self-sterile and require pollinators for fruit to set (McGregor 1976). In guava besides self-pollination, cross-pollination is a general rule (Dasarathy 1951). In this chapter an attempt has been made to review the literature on the various pollination studies focusing on different aspects of pollinators in litchi and guava.

2.1 Initiation and cessation of flowering

2.2 Diversity of insects

2.3 Foraging behavior of insects

2.1 Initiation and cessation of flowering

Guava blooms twice a year, *i.e.* in April-May and August-September and fruits appear in rainy and winter seasons respectively (Gupta and Nijjar 1978). A third flowering although sparse also has been reported to occur in October-November (Hayes 1974; Singh and Kumar 1993).The blooming period has been reported as 28 to 45 days depending upon cultivar, season and region of growing (Mitra and Bose 1990).

In litchi, from flower initiation to anthesis, the blooming period has been reported as 2 to 6 weeks (Chadha and Rajpoot 1969; Sarkar and Bandyopadhyay 1989; Menzel 2001).

2.2 Diversity of pollinating insects

Insects form a major group of biotic pollen dispersal agents of different agricultural and horticultural crops. Among insects, hymenopterans constitute a vast multitude of most efficient pollinators of horticultural crops like honeybees and bumblebees. Buchmann and Nabhan (1996) have documented from the United States of America that 14,126 species of Diptera are involved in the process of pollination in the tropical world. Inouye (2001) opined that dipteran flies were the second predominant insects after hymenopterans on crops in the USA.

In Litchi, Bhatia et al. (1995) has documented 34 species of pollinators from Himachal Pradesh belonging to the order Diptera, Hymenoptera and Coleoptera. Jarlan et al. (1997) has reported *Eristalis tenax* (Syrphidae) as one of the most efficient pollinators of litchi flowers.

Araujo et al. (2006) documented 91 bee species from Brazil of which Apidae was the most abundant followed by Halictidae and Megachilidae families. The minor insects were from the families Colletidae and Andrenidae.

Frund et al. (2010) reported mutual specialization between pollinators and floral diversity. Raj et al. (2012) studied diversity and relative abundance of various insect visitors in apple crop and reported 46 species insect diversity at different locations in Himachal Pradesh. They also have reported Indian hive bee, *Apis cerana* as the most abundant insect visitor to apple flowers. Sharma and Mitra (2012) have reported 63 pollinator insect species under 27 families of 6 insect orders from 7 temperate fruit crops of Himachal Pradesh. Thakur and Mattu (2014) studied the diversity and distribution of different insect visitors on apple, pear, cherry, plum and almonds and have reported 70 species of insect visitors belonging to 6 orders and 27 families. Sharma et al. (2015) studied pollinator diversity and documented that it played an important role in fruit set in apple orchards augmented with honeybee (*Apis mellifera*) colonies. They also studied flowering phenology, pollinator diversity, supplemented pollination and their impact on fruit set in apple under changing climatic scenario in Kullu district of Himachal Pradesh. Sharma et al. (2016) while studying diversity of insect visitors in cherry at Solan different sampling methods, namely fluorescent pan traps, scan sampling and sweep net and reported 20 insects belonging to 18 genera under 10 families and 5 orders from cherry bloom. Among all insects, *A. mellifera*, *A. cerana* and *Episyrphus balteatus* were most frequent visitors. Sharma and Mitra (2012) have documented 63 species under 27 families of 6 insect orders from insect pollinator studies in 7 temperate fruit crops of Himachal Pradesh.

Mogren et al. (2016) have recommended that discouraging the practice of monocultures and incorporating pollinator-friendly crops at the farm level is an essential tool to enhance pollinator diversity.

Widhiono et al. (2016) has documented the various niches for rich diversity of wild bees and wasps in different seven habitat types from Indonesia *viz.*, natural forest, teak forest, pine forest, *Agathis* forest, community forest, gardens, and agricultural areas. Mushtaq et al. (2017) have documented the diversity and abundance of various native pollinators in apple from three districts of Kashmir valley.

Nayak et al. (2019) carried out studies on utilization of bumble bees (*Bombus haemorrhoidalis*) and European honeybees for the pollination of kiwifruit var. Allison under caged condition at kiwifruit orchard Solan. It revealed that bumble bees visited more number of flowers per minute than honeybees and added that honeybees took more time for completing a single foraging trip and spent significantly more time per flower than bumble bees. Mani and Sarvanan (1999) have reported that pollination studies would pertain to pronounced bias towards honeybee pollination in agriculture and horticultural crops in India. They also added that on the contrary, very little attention has been given to the insects of Diptera.

2.2.1 Litchi

There are a number of insect species visiting the litchi bloom. Srivastava et al. (2017) have documented 20 pollinator species of three orders, Diptera, Hymenoptera and Coleoptera in Litchi. They have also reported that honeybee species (*A. dorsata, A. mellifera, A. cerana, A. florea*) were the most efficient ones as well as predominant pollinators (up to 65 %) of litchi. Out of all the pollinators *A. mellifera* had the highest visitation frequency of 9.66 foragers/panicle/5 min. Earlier, Abrol (2006) had also documented honeybee species as most abundant pollinators. The other pollinators visited were *Xylocopa fenestrata*, *X. arustans*, *Halictus* spp., *Nomia* spp., *Vespa orientalis*, *V. cincta*, *Polistes hebraeus*, *Megachile lanata*, *Camponotus compressus*, *Musca* spp., *Eristalis* spp.

Usha et al. (2009) have documented honeybees as major visitors of litchi and the Hymenopteran insects were the most predominant visitors (61.26 %).

Earlier, the Indian honeybee (*A. cerana indica*) was the dominant pollinator for litchi, but recently the European honeybee *A. mellifera* is being widely used commercially as an efficient pollinator of litchi (Kumar and Kumar 2014).

In a study conducted in Nepal, the litchi crop was visited by 21 insect species *viz.*, *A. mellifera*, *A. cerana*, *A. dorsata*, *Chiloloba acuta*, *Coccinella* spp., *Agriocnemis* spp., *Musca domestica*, *Agrophalyx nigrotibitalis*, *Leptocorisa acuta*, *Eristalis* spp., *Tabanus* spp., *Pieris* sp., *Papilio machaon*, *Lampides boeticus*, *Cyntomis passalis*, *Vespa orientalis*, *V. magnifica*, *Sphex* sp., *Ergolis merione*, *Danaus plexippus* and Crane fly. (Thapa 2002; Dhakal 2003; Neupane 2001; Devkota 2000).

2.2.2 Guava

Abundance of insect visitors on the bloom of different crops depend upon the geographical distribution, climatic conditions, availability of natural sites for nesting, and the relationship between the plant and the insect species (Dashad 1989). In tropical and subtropical areas, summer and rainy seasons are very harsh for bees (Mishra and Sharma 1998).

Earlier studies on diversity of insect fauna have revealed that the honeybees (McGregor 1976; Roubik 1995) and various other insects visited guava blossom (Crane and Walker 1984). In Punjab, *A. mellifera* and *A. cerana indica* were documented as major pollinators which visited the guava blossoms for nectar and pollen (Srawan and Sohi 1985).

Hedstrom (1988) reported different flower visitors on guava *viz.*, *Apis mellifera*, *Bombus mexicanus*, *Trigona* spp., *Lasioglossum* spp., *Trigona cupria* and

Xylocopa spp. Kuberappa et al. (2002) also reported several visitors that comprises five species of honeybees *viz.*, *A. mellifera*, *A. dorsata*, *A. cerana indica*, *A. florea* and *Trigona iridipennis* (Apidae) and one species each of Megachilidae and Xylocopidae *viz.,*, *Megachile lanata* and *Xylocopa fenestrata*, respectively. Among insect pollinators of guava, honeybees are the most predominant ones (Hedstrom 1988; Hussain 2011).

Mann and Dhooria (1994) in Punjab reported large brown syrphid moth, *A. dorsata, A. florea* and yellow wasp as the common visitors of the guava flowers. Among these *A. dorsata* was the dominant visitor.

In studies carried out in Brazil *Bombus morio, Bombus atratus, A. mellifera*, *Nannotrigona punctata*, *Trigona spinipes* and *Melipona scutellaris* were the predominant species documented on guava blooms (Camillo and Garofalo 1989; Castro and Araujo 1998).

Singh and Garg (2003) have documented guava as an important bee pollinated crop. Laxmi and Rao (1998) studies reveal that guava flowers were frequently visited by honeybees for heavy yields of pollen but moderate nectar.

Freitas and Elves (2008) listed the floral visitors on the Paluma cultivar of guava which included *A. mellifera*, *Melipona subnitida*, *Partamona cupira*, *Trigona spinipes* and *Xylocopa* spp.

Mehta (2009) during pollination studies on guava also documented 15 insect species in spring season which included *Apis dorsata*, *A. mellifera, A. cerana, A. florea, Xylocopa*, *Halictus, Vespa aurientalis, Sarcophaga* sp., *Chrysomya bezziana, Musca* sp., *Syrphus* sp., *Eristalis* sp., Tachinid fly, *Coccinella septempunctata, C. septembipunctata* and *Lampides boeticus.* Insect visitors in autumn season included one wasp, one pentatomid bug and *Pieris brassicae*.

2.3 Foraging behavior of insects

Literature pertaining to different foraging attributes of honeybees on both the crops for their foraging attributes *viz.*, foraging intensity, foraging rate, foraging speed, foraging mode and pollination efficiency index.

2.3.1 Foraging intensity

The majority of flowering plants rely upon pollination by insects, consequently their reproductive success depends on insect behavior. The foraging behavior of insect pollinators is flexible, yet complex as efficient collection of pollen or nectar is no simple task. Foraging strategies of visiting pollinators determine the pollination potential of the plants they visit. There was a positive correlation between the plant height, flower petal size and intensity of visitation by *A. mellifera* indicating preference for larger flower sized plants (Omoloye and Akinsola 2006).

In litchi, honeybees were most abundant between 0630 hrs. and 1200 hrs. when anther dehiscence occurs (Das and Choudhary 1958). Pandey and Yadava (1970) reported that *A. dorsata, A. cerana, A. florea and Melipona* spp., constituted 98 to 99 per cent of insect visitors, but hover flies, black ants, *Musca* spp. and *Vespa* spp. are regular visitors of litchi flowers.

Phadke and Naim (1974) observed that *Apis florea* and *Apis cerana* constituted about 18-60 per cent visits to litchi blossoms in Bihar. Dhaliwal et al. (1977) reported that *A. florea* and *A. cerana* constituted about 50-60 per cent visits to litchi blossoms in valley areas of Indian Himalayas.

Adlakha et al. (1979) reported *A. florea* as the most frequent visitor followed by *A. cerana* on litchi in Himachal Pradesh. Intensity of foragers and their thresholds for foraging are influenced by the nature of crop, bloom visited, possibly through the phenomenon of anthesis and/or rhythm of nectar and/or pollen presentation and weather factors (Free 1993).

Mann and Dhooria (1994) reported 74-93 per cent activity of *A. dorsata* in guava between 0700 to 0800 hrs. and no activity during 1300 to 1700 hrs. at Ludhiana, Punjab. This trend of peak foraging activity recorded in morning hours can be attributed to the abundant availability of pollen during morning hours compared to afternoon hours. Guava flowers are frequently visited by honeybees, out of which *A. mellifera* constituted 44.6 per cent whereas *A. dorsata* and *A. cerana indica* form 35.2 per cent combined, respectively (Kumar et al. 1996).

Kumar et al. (2000) studied the floral biology and pollination in orchard of litchi and found that *A. mellifera* was the most abundant (44.8 % of total), followed by *A. dorsata* (20.7 %) and *Trigona iridipennis* (18.9 %). Boti et al. (2005) also gave list of most abundant pollinators in guava *viz*., *A. mellifera*, *Trigona spinipes*, *Epicharis flava*, *Euglossa* sp., *Centris tarsata*, *Augochloropsis patense* and *Xylocopa frontalis*.

Rajagopal and Eswarappa (2005) revealed the per cent proportion of pollinators on the guava flowers in which honeybees accounted for 92.86 per cent and other pollinators only 7.14 per cent. Among honeybees, *A. dorsata* (46.58 %) and *A. mellifera* (37.99 %) visited the flowers most frequently. In Salinas, Brazil, Rosemeire et al. (2009) recorded 17 species of pollinators on guava, most frequent being *Trigona spinipes*.

Mehta (2009) documented the relative abundance of insect visitors of guava in spring and autumn seasons. During the spring season the abundance of *A. florea* (2.86 bees/m^2) was maximum followed by *A. dorsata* (2.26 bees/m^2), dipterans (1.27 insects/m^2), *A. mellifera* (1.03 bees/m^2) and *A. cerana* (0.48 bees/m^2). But during the autumn season the abundance of *A. dorsata* (1.80 bees/m^2) was recorded maximum followed by *A. florea* (1.54 bees/m^2), dipterans (1.09 insects/m^2), *A. mellifera* (0.78 bees/m^2) and *A. cerana* (0.49 bees/m^2).

Joshi and Joshi (2010) reported that *A. cerana* was more frequent pollinator of apple blooms than *A. mellifera* at Nainital, Uttrakhand. Pollination studies conducted on guava at GKVK Bangalore, suggested that *A. dorsata*, *A. cerana* and *A. florea* have foraging rates of 8.00, 5.33 and 5.00 bees/5flower/5minutes, respectively (Hussain 2011). According to him, the mean foraging activity of honeybee pollinators under open conditions during May month in guava crop was maximum for *A. dorsata* (2.07 bees/5flowers/5min.) when compared to *A. cerana* (1.65 bees/5flowers/5min.) and *A. florea* (1.59 bees/5flowers/5min.).

2.3.2 Foraging rate

The number of flowers visited by an insect species depends upon the type of bloom and the density of flowers on a particular cultivar of a crop (Free 1970). Some findings revealed that the length of the proboscis of the insect was also involved in the determination of the rate of foraging by the pollinators (Inouye 1980).

A. cerana indica, *A. florea* and *Trigona* sp. visited 2.00, 1.40 and 1.30 umbels and 5.90, 6.40 and 2.60 florets of onion per min., respectively (Rao and Lazar 1980). Maeta and Kitamura (1981) observed *Osmia cornifrons* to work faster (2450 flowers/day) than honeybees (30 flowers/day) on apple flowers. Tanda (1983) recorded that *A. cerana indica*, *A. mellifera* and *A. dorsata* to visit 4.50, 5.70 and 5.50 cotton flowers per minute, respectively.

Several investigators have documented that *A. cerana* visits more number of flowers per minute and spends less time per flower as compared to *A. mellifera* on apple (Verma and Dulta 1986); plum (Rana 1989); peach and almond (Kumar 1995) and wild cherry (Kumar 1997) crops.

Similar studies by Kumar and Gupta (1993) in Solan hills revealed that *A. cerana* visited more number of flowers of apple, apricot and almond than *Apis mellifera* but latter species visited more flowers of *Brassica* sp., plum and peach than former.

Mehta (2009) documented that the foraging rate of hymenopteran insects were significantly higher than those of dipterans in the *guava*. In both spring and autumn season, the foraging rate was found to be maximum for *A. cerana* followed by *A. mellifera*, *A. dorsata*, *A. florea* and the least was seen for Diptera. Foraging rate of *A. cerana* and *A. mellifera* on apple at Nainital was 10.71 ± 0.7 flowers per minute and 8.44 ± 0.2 flowers/minute respectively, which evidently shows that *A.cerana* visited higher number of flowers than that of *A. mellifera* (Joshi and Joshi 2010).

2.3.3 Foraging speed

Kumar and Gupta (1993) documented that in apple, almond, apricot, *Brassica*, plum and peach crops *A. mellifera* spent more time on each flower when compared to *A.cerana*. Studies conducted on the foraging speed of *A. dorsata* on guava flowers at three different stages, revealed that the time spent on unopened, half opened and an opened flower was recorded as 8, 18 and 23 seconds, respectively (Mann and Dhooria 1994).

During pollination studies in guava, Kumar et al. (1996) observed the time spent by each honeybee species per flower and recorded highest foraging speed in case of *A. mellifera* (5.8 sec.), followed by *A. dorsata* (5.2 sec.) and *A. cerana* (4.0 sec.). Similar studies by Rajagopal and Eswarappa (2005) in guava at Karnataka revealed that *A. florea* (108 sec./flower) and *Trigona iridipennis* (28.68 sec./flower) spent maximum and minimum mean time for pollen collection compared to other bee species.

Joshi and Joshi (2010) observed that *A. mellifera* has significantly higher (7.43 ±0.8 sec./flower) foraging speed (time spent on apple bloom) than *A. cerana* (5.11 ± 0.9 sec./flower) on apple at Nainital. Hussain (2011) also found that the maximum mean time spent by honeybees on guava flowers for pollen collection was by *A. florea* (8.58 sec./flower) followed by *A. cerana* and *A. dorsata* (5.32 and 4.74 sec./flower, respectively).

On litchi the foraging speed (time spent in sec./flower/forager) was recorded maximum during morning hours while, minimum during afternoon hours for all the honeybees. The mean foraging speed was found to be maximum for *A. dorsata* (4.64 sec.) while *A. florea* (3.32 sec.) showed lowest foraging speed (Das et al. 2019).

2.3.4 Foraging mode

Behavior of insect pollinators on individual plant or tree crop, during bloom period, is likely to vary according to the rewards offered, the size and complexity of floral displays, distribution of reward offered by other plant species and the abundance and behavior of other flower visitors (Goulson 1999). Pollen gatherers spent less time per flower and visited more flowers per tree than nectar collectors.

Robinson (1979) noticed different techniques of working, employed by the honeybee foragers on Delicious cultivar of apple. Workers standing with all legs on anthers, parting the stamens head down, wherein proboscis extends to the nectar were called top foragers. Workers with all the legs standing on petals, reaching between filaments with tongue were categorized as side workers. He also found that on 5 cultivars other than Delicious, 60.70 per cent of nectar foragers were top workers, 33 per cent were spreaders and 6.30 per cent, the side workers. In contrast, in Delicious nectar foragers were 13.30 per cent top workers, 0.70 per cent spreaders and 86 per cent side workers. These differences in the foraging behavior of honeybees could be explained in terms of floral morphology.

Mayer and Lunden (1988) measured time spent per flower as 8.4, 6.9 and 11.0 seconds for top worker, side worker and pollen collectors on Manchurian apple and 12.1, 6.6 and 10.7 seconds respectively on its Delicious cultivar.

Verma and Rana (1994) found that the proportion of top workers was similar for the two bee species *A. cerana* and *A. mellifera* during each observation for foraging mode in apple blooms. For both species, more bees worked from the top position (on the stamens) at 0900 hrs. but from the side position (on the petals) at 1500 hrs.

According to Ahmad et al. (2017) there were fluctuations in the percentage of top and side worker bees of *A. cerana* and *A. mellifera* on apple bloom. Top workers of both *A. cerana*, 41.67, 42.67 and 47.33 per cent and *A. mellifera*, 38.67, 42.33 and 45.67 per cent differ from side workers of these species with 58.33, 57.33 and 52.67 per cent for *A. cerana* and 61.33, 57.67 and 54.33 per cent for *A. mellifera* respectively at all the three orchards. The average hourly ratio of top workers to side workers was 1:1.39, 1:1.34 and 1:1.11 for *A. cerana* at 0900, 1200 and 1500 hours of the day, whereas, the ratio of top workers and side worker for *A. mellifera* was 1:1.58, 1:1.36 and 1:1.18 respectively. Interspecific comparison between *A. cerana* and *A. mellifera* with regards to the top as well as side workers showed no significant ($P>0.05$) differences.

2.3.5 Pollination efficiency index

The term pollination efficiency (PE) is the better estimate of the effectiveness of a pollinator species as the average number of flowers actually pollinated by a forager per unit time specific to a species as a whole. PE is the result of three parameters *viz.*, (a) foraging mode (b) foraging rate and (c) population abundance of a pollinator species on a plant species (Sihag 1997). Other contributing factors considered pertinent in determining the relative importance of anthophilous insects as pollinators, are body size, hairiness and the amount of loose pollen grains sticking to the body (Anderson et al. 1982). Amount of loose pollen on the body varies with the plant species and the species of insects that are foraging. In almond, pollen foragers of *Apis cerana indica* and *A. mellifera* carried 2898 and 3852 whereas nectar foragers accounted 1974 and 2574 pollen grains on their bodies, respectively (Singh 1988).

Percentage of pollen load in relation to body weight of a bee was maximum in summer (24.64 %) and minimum in winters (9.94 %) season in apple (Mattu 1982). Many investigators have observed that worker bees of *A. mellifera* carried significantly heavier pollen loads than *A. cerana* from different crops like apple (Verma and Dulta 1986); plum (Rana 1989); *Plectranthus rugosus* (Sharma 1989); peach and almond (Kumar 1995) and wild cherry (Kumar 1997).

Kitroo and Abrol (1996) made observations on litchi for pollen carrying capacity by four honeybee species *A. mellifera, A. dorsata, A. cerana* and *A. florea*. They recorded that the pollen load varied from a minimum of 4.7 mg (*A. florea*) to a maximum of 14.2 mg (*A. dorsata*). Mehta (2009) documented that in the spring season, irrespective of the guava variety, the average number of loose pollen grains was maximum (6499.99) on the body of *A. dorsata* followed by *A. mellifera* (4686.66), *A. cerana* (4254.65) and *A. florea* (2554.73). Similar trend was followed in autumn season where average number of loose pollen grains was maximum (6479.99) on the body of *A. dorsata* followed by *A. mellifera* (4649.34), *A. cerana* (4211.98) and *A. florea* (2484.72).

Joshi and Joshi (2010) observed pollen loads in honeybee species on apple and found that *A. mellifera* carried heavier pollen loads than that of *A. cerana*. Freitas and Alves (2008) have reported from Brazil the importance of honeybees in guava and also have documented that two visits per flower of *A. mellifera* had the best pollination efficiency index. Hussain (2011) found that out of three honeybee species, the mean pollen carrying capacity was higher in *A. dorsata* (14.5 mg) followed by *A. cerana* (6.4 mg) and *A. florea* (2.8 mg).

3. MATERIALS AND METHODS

The present study entitled "Pollination potential of *Apis* species on guava and litchi" was carried out at Bee Research Station, Nagrota Bagwan of Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, District Kangra, Himachal Pradesh, India during the year 2019-20.

The study was conducted with an aim to generate information on relative abundance and foraging behavior of insect pollinators on guava and litchi. The foraging attributes under study were foraging intensity, foraging rate, foraging speed, foraging mode and pollination efficiency index. The assessment of these attributes of pollinators was carried out for litchi at following locations *i.e.* Palampur (1472 m amsl), Nagrota Bagwan (870 m amsl), Sulah (434 m amsl) and Saliana (1276 m amsl) and for guava at Palampur, Bharwar (489 m amsl) and Jachh (428 m amsl) of the Kangra district. The materials used, techniques and methods adopted for recording observation is discussed in this chapter.

3.1 Sampling sites

For assessment of population dynamics of pollinators in litchi and guava, following few sites having their respective orchards in Kangra were investigated. For litchi, these sites were Palampur, Sulah and Nagrota Bagwan and Saliana. For guava sampling sites included Palampur, Bharwar and Jachh.

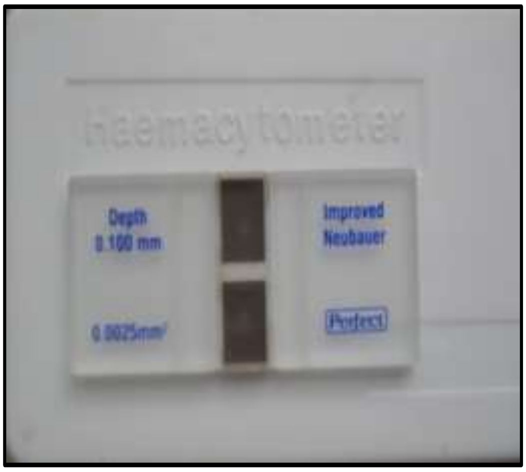
3.2 Experimental materials

3.2.1 Materials for recording relative abundance and other foraging characters

i) Cell phone: Record time to count insects on selected canopy and their number in unit time for relative abundance, foraging intensity, foraging rate and foraging speed of insects was determined by inbuilt stopwatch in the cell phone model Lenovo K6 Power.

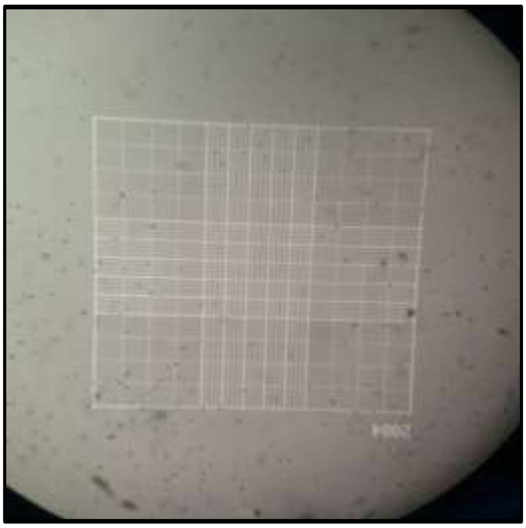
ii) Insect collecting net: It is made up of mosquito netting material having a hoop with diameter 30 cm and used for catching insect pollinators on both litchi and guava trees.

(a)



(b)

(c)



(d)

Plate 3.1 Microscope and other materials used for counting pollen grains

- **(a) Stereo zoom microscope NIKON SMZ 1500**
- **(b) Haemocytometer**
- **(c) Honeybee sample in 70 percent ethyl alcohol**
- **(d) Counting chamber of Haemocytometer**

(a)

(b)

(c)

(d)

Plate 3.2 Guava bloom in the orchard with prevalent visitors

- **(a) Guava flower and bud**
- **(b) Top worker of *Apis dorsata***
- **(c) Side worker of *A. dorsata***
- **(d) Syrphid flies**


(a)


(b)


(c)


(d)


(e)


(f)


(g)


(h)


(i)

Plate 3.3 Predominant visitors and stages of litchi bloom

(a) Selected canopy in early bloom

(b) Peak bloom

(c) Fruit set

(d) Pea stage of fruit

(e) *Apis mellifera*

(f) *Apis cerana indica*

(g) Coccinellid feeding on pollen

(h) Syrphid fly

(i) *Polistes* sp.

iii) Insect killing bottles: Cotton soaked with ethyl acetate as a killing agent in airtight glass jar used for killing collected insect pollinators.

iv) Record book: To note down the data and information collected in the orchards.

v) Camera: For close up photographs NIKON COOLPIX L310 21X optical zoom camera and Canon SX740 HS camera were used alternatively in orchards to record activity of the visiting pollinators and images on the flowers of litchi and guava. Images of pinned insects were also taken.

3.2.2 Materials for preservation of collected insects

i) Ethyl acetate: It is an organic compound which was used as a poison in killing bottles for collected insects from the orchards.

ii) Insect collection box: The collected and killed insects were safely preserved inside a glass topped wooden box with dimensions 45×30×15 cm.

iii) Ethyl alcohol (70 %): Used for wet preservation of some of the pollinators.

iv) Microscope: A stereo zoom microscope (Model NIKON SMZ 1500) was used to magnify the pollens to count them and to take photographs.

v) Haemocytometer: This specialized slide generally used to count blood cells, was used to count the number of pollen grains in a standard volume of liquid containing pollen grains.

3.3 Miscellaneous

Entomological pins, naphthalene balls, glass vials, insect spreading board, forceps, camel hair brush, needles, magnifying glass, pipette, razor blade, counting dish *etc*. were also used during the study for various purposes.

3.4 Methodology

The experimental methods adopted and procedures followed during the course of this investigation are being described below under the following heads and subheads:

3.4.1 Relative abundance of insects on crops

In the selected locations and fruit trees chosen for survey a total number of visiting insects/m^2 on the randomly selected canopy area of each tree at early and peak bloom periods were counted for one minute twice a day *i.e.,* in morning (1000-1100 hrs.) and afternoon hours (1400-1500 hrs.) in three replications twice a week as per the method given by Amin et al. (2018) with slight modifications was used. Each count of different pollinators was assessed to work out their relative abundance at different survey locations namely Palampur, Nagrota, Sulah and Saliana in case of litchi crop and similarly Palampur, Bharwar and Nurpur for guava as per the method adopted by Das and Jha (2018).

$$\text{Relative abundance (\%)} = \frac{(\text{Population of a specific species visiting flowers})}{(\text{Total population of all species visiting flowers})} \times 100$$

For assessing the insect's information, the branches of these trees were chosen in such a manner, that they had approximately the same dimensions with respect to their spread, phase of flowering, number of flowers and height above ground. Early bloom duration in the two crops was decided to be initial 10 days while peak bloom of flowering was considered the time when there was around 50 per cent opening of flowers in the selected fruit tree. The data was recorded on four branches from three trees each for litchi and guava in each location covering all possible directions (Anita et al. 2012; Kaur and Sharma 2020).

3.4.2 Foraging behavior of insects

Different aspects of foraging behavior of the honeybees on both the crops were studied following the methods given below:

i) Foraging intensity

It was recorded twice during the entire blooming period *i.e.,* early bloom and at peak blooming as number of insects per selected canopy of tree per minute (Bajiya and Abrol 2017).

ii) Foraging rate

It was recorded as the number of flowers visited by different species of honeybees on each tree per minute including flying time from one flower to another (Dalio 2018; Sharma et al. 2018).

iii) Foraging speed

Observations were taken in terms of the time (in seconds) spent by each bee species on a single flower of litchi and guava as per Free (1993) with slight modifications. The time spent to insert the proboscis and suck up the nectar or brushing/collecting pollens was considered as time spent per flower (Rani et al. 2017). Foraging speed (time spent per flower) and foraging rate (number of flowers visited per min.) depend upon the foraging behavior of insects and floral structure of the crop concerned (Free 1970) particularly the corolla depth (Gilbert 1980).

iv) Foraging mode

It was calculated as the ratio of top foragers and side foragers as per Verma and Rana (1994) with slight modifications. To record data, 20 honeybees of each species were observed on the inflorescence of litchi and guava separately.

v) Counting number of pollen grains from body and hind legs (corbicular pollen loads) of honeybees

The pollen grains on hind legs and loose pollen grains sticking to the body of 5 honeybees of each species were counted by individually capturing bees using forceps. The hind legs were amputated and brushed by camel hair brush in vials containing 70 per cent ethyl alcohol as per the method given by Kumar (1990). These pollen grains were suspended in 5ml of 70 per cent ethyl alcohol and shaken for 30 seconds to get a homogenous mixture. 1 µl of each sample of pollen suspension was pipetted out in the haemocytometer and examined under a stereo zoom microscope. The number of pollen grains in suspension was calculated using the following formula,

Total number of pollen grains = Average number of pollen grains counted in WBC

per bee per 5 ml of solution chamber × 5 ml × 10^4

vi) Pollination efficiency index

Pollination efficiency of honeybee pollinators was calculated based on their relative abundance, foraging rates and number of loose pollen grains sticking to their bodies (Bohart and Nye 1960). Log_{10} values of pollination efficiency were determined further for ease of ranking. Counting pollen grains with the aid of a haemocytometer is one of the oldest, least expensive and accurate techniques, which was employed for the purpose.

Pollination efficiency = Abundance of insect pollinators on flowers × Foraging rate × Number of loose pollen grain sticking on the body of insect

Ranking based on P.E.I. was done to screen out the most efficient pollinator among them.

3.5 Collection and identification of insects

Insects were either hand collected or sweep net collection was performed. These specimens were poured in a killing bottle containing swap of ethyl acetate (Dar et al. 2018). The specimens from each site were well labeled with all the requisite information and taken to the laboratory for preservation and identification. These insect specimens were identified from ICAR-IARI, New Delhi.

3.6 Statistical analysis

The data collected was analyzed by two factorial RBD in CPCS1 software. The critical differences between the treatments were worked out at five per cent significance level.

4. RESULTS AND DISCUSSION

The results obtained in the present investigation have been presented and discussed under the following heads:

4.1 Initiation and cessation of flowering

Bloom in Culcuttia variety of litchi was observed on 4th of April in 2019 with its peak bloom on 12th of April and termination of flowering period noticed on 28th April, 2019. During this year due to incessant rains and prevailing low temperature, the flower initiation was delayed as it usually appears in February-March. In guava variety Allahabad Safeda, flower initiation was observed on 26th of April and blooming continued up to 3rd June during the year 2020 at Jachh. Flower initiation in guava at Palampur site in the same variety was seen on 1st May and terminated on 8th of June, 2020. Usually, guava blooms in April-May (Gupta and Nijjar 1978).

4.2 Diversity of pollinating insects

The observation on the number of insect foragers on selected canopy of three trees of litchi in orchards was recorded twice in a day at 1000-1100 hours and 1400-1500 hours. The visiting insects were critically observed and their counts were recorded in one minute on one tree. The data were recorded on the insect visitors at two blooming periods *i.e.* 10 per cent (early) and peak bloom during April to May, 2019 at four locations in litchi crop. Similar observations during May to June, 2020 were also recorded in guava at three different locations. A number of insect visitors were recorded in litchi ecosystem and table 4.1 depicts the diversity of insect fauna. The plates 4.1a, 4.1b and 4.2 show important Hymenopteran, Dipteran, Lepidopteran and Coleopteran visitors of guava and litchi.

Table 4.1 Diversity of insect visitors of litchi in Kangra during 2019

Sr. No.	Insect species	Order	Family	Location
1.	*Apis mellifera*	Hymenoptera	Apidae	Saliana
2.	*Apis cerana indica*	Hymenoptera	Apidae	Saliana
3.	*Apis dorsata*	Hymenoptera	Apidae	Palampur
4.	*Bombus haemorrhoidalis*	Hymenoptera	Apidae	Sulah
5.	*Megachile* sp.	Hymenoptera	Megachilidae	Sulah
6.	*Polistes* sp.	Hymenoptera	Vespidae	Saliana
7.	*Pimpla* sp.	Hymenoptera	Ichneumonidae	Palampur
8.	*Eristalodes paria*	Diptera	Syrphidae	Sulah
9.	*Eristalis tenax*	Diptera	Syrphidae	Palampur
10.	*Eoseristalis arbustorum*	Diptera	Syrphidae	Nagrota
11.	*Eristalinus arvorum*	Diptera	Syrphidae	Saliana
12.	*Scaeva latimaculata*	Diptera	Syrphidae	Sulah
13.	*Episyrphus balteatus*	Diptera	Syrphidae	Nagrota
14.	*Melanostoma* sp.	Diptera	Syrphidae	Sulah
15.	*Episyrphus viridaureus*	Diptera	Syrphidae	Nagrota
16.	*Coccinella septempunctata*	Coleoptera	Coccinellidae	Nagrota
17.	*Oenopia sexareata*	Coleoptera	Coccinellidae	Saliana
18.	*Symbrenthia* sp.	Lepidoptera	Nymphalidae	Sulah
19.	*Pieris brassicae*	Lepidoptera	Pieridae	Sulah

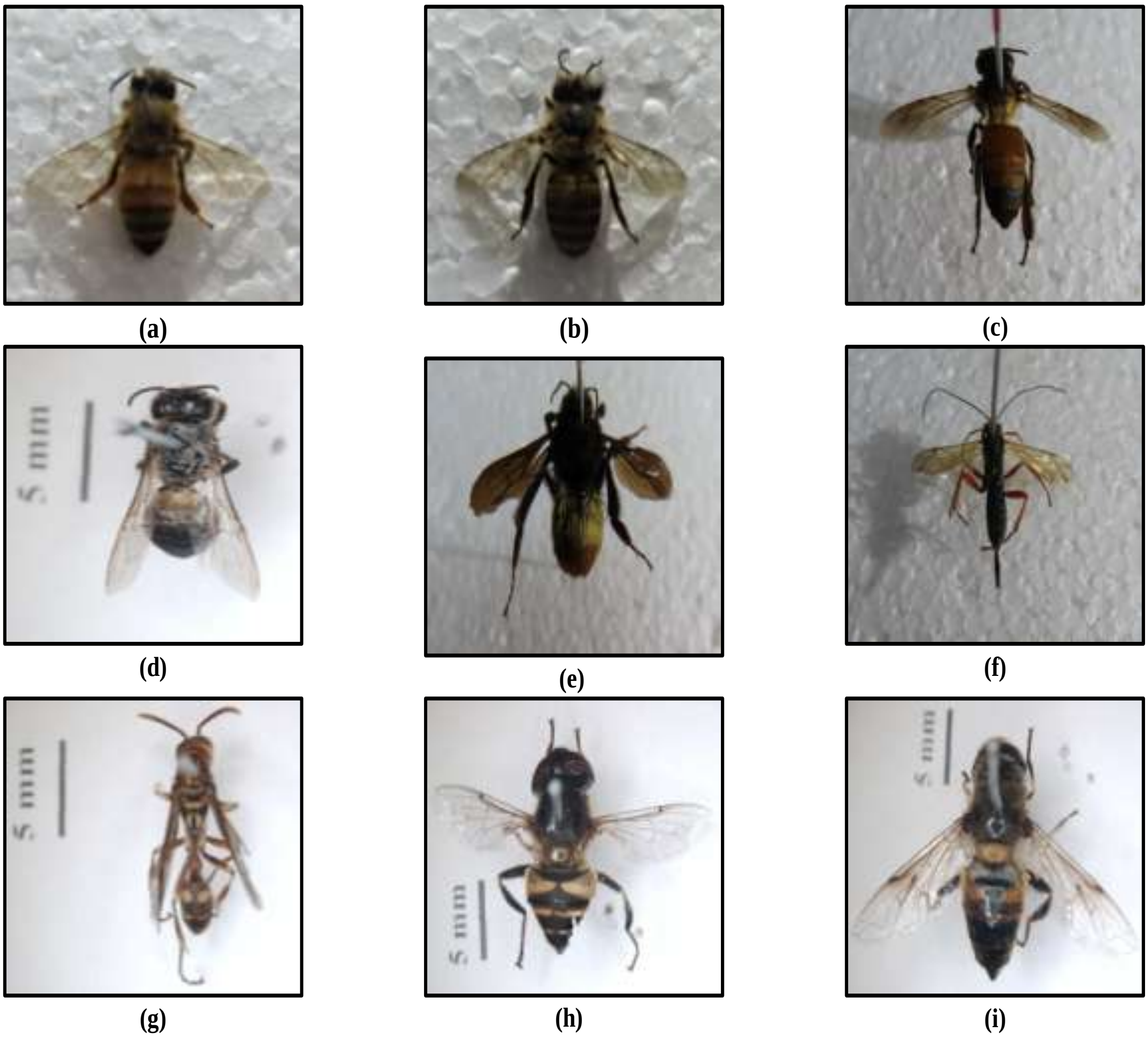


Plate 4.1a Hymenopteran and Dipteran visitors of litchi and guava

- **(a)** ***Apis mellifera***
- **(b)** ***Apis cerana indica***
- **(c)** ***Apis dorsata***
- **(d)** ***Megachile* sp.**
- **(e)** ***Bombus haemorrhoidalis***
- **(f)** ***Pimpla* sp.**
- **(g)** ***Polistes* sp.**
- **(h)** ***Eristalodes paria***
- **(i)** ***Eristalis tenax***

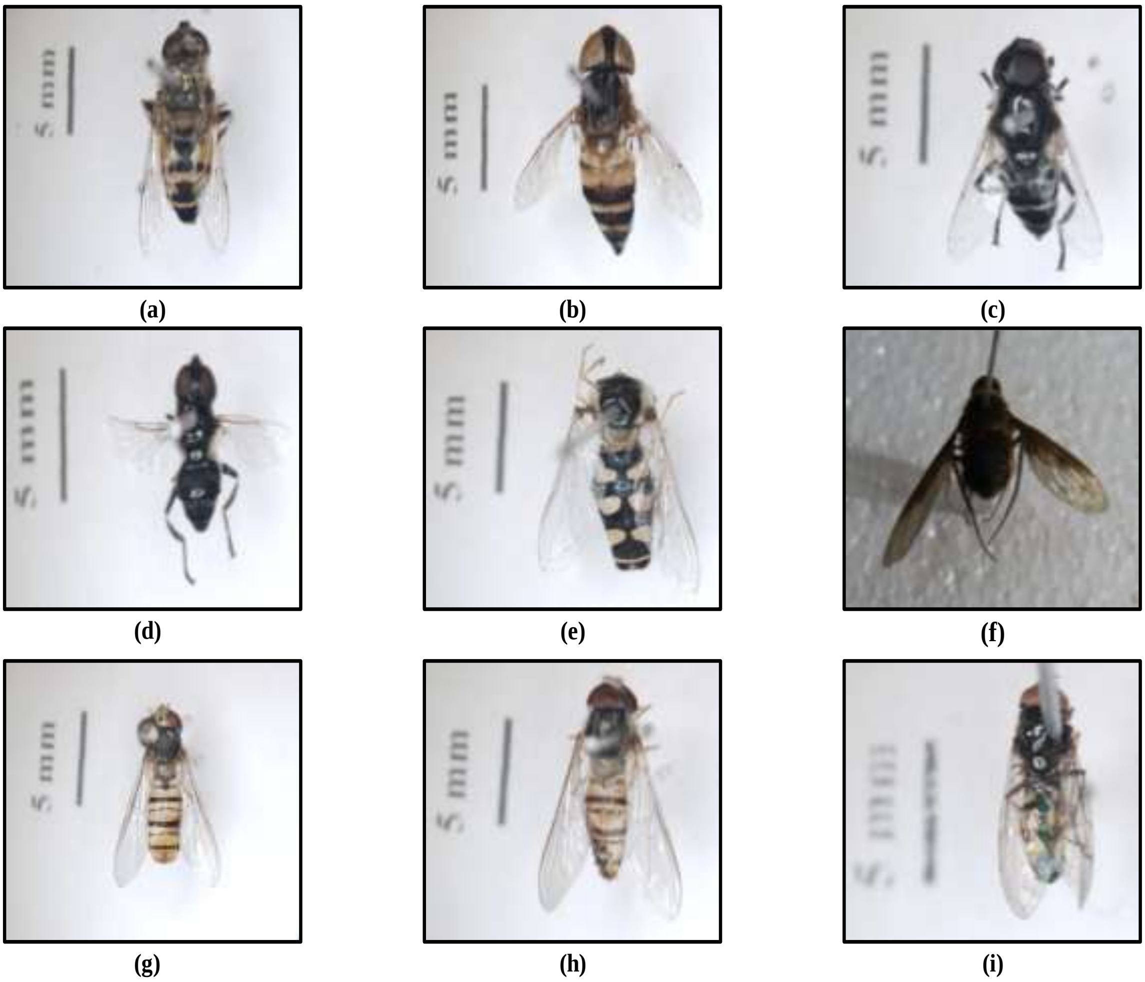


Plate 4.1b Dipteran visitors (Syrphid flies) of litchi and guava

(a) ***Eoseristalis arbustorum***

(b) ***Eristalinus arvorum***

(c) ***Eristalis* sp.**

(d) ***Paragus* sp.**

(e) ***Scaeva latimaculata***

(f) ***Exoprosopinae***

(g) ***Episyrphus viridaureus***

(h) ***Episyrphus balteatus***

(i) ***Melanostoma* sp.**

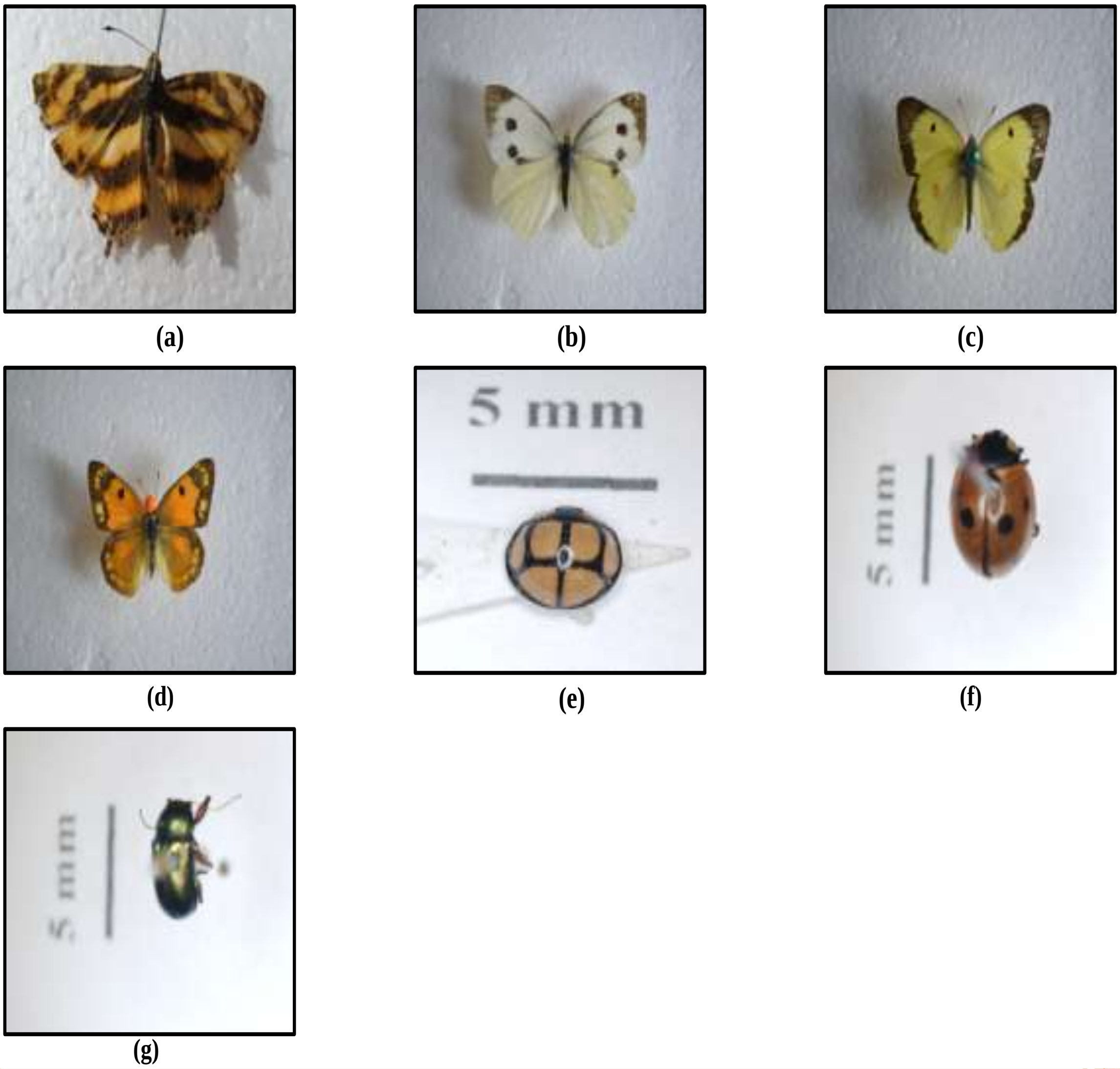


Plate 4.2 Lepidopteran and Coleopteran visitors of litchi and guava

(a) ***Symbrenthia*** **sp.**

(b) ***Pieris brassicae***

(c) ***Colias philodice***

(d) ***Colias crocerus***

(e) ***Oenopia sexareata***

(f) ***Coccinella septempunctata***

(g) ***Colasposoma lividipes***

4.2.1 Relative abundance of insects

i) Foraging intensity and relative abundance of insects in litchi

The number of insects visiting a selected area of the plant in one minute was recorded during morning 1000-1100 hours and afternoon 1400-1500 hours at four locations.

(a) Early bloom

It is evident from table 4.2 that a significant interaction between locations and insect pollinators is present. The highest mean foraging intensity was at Sulah (0.48 insects/m^2/min.), followed by Nagrota (0.35 insects/m^2/min.), Saliana (0.35 insects/m^2/min.) and Palampur (0.13 insects/m^2/min.) during morning hours. In the afternoon a similar trend with comparatively low population, Sulah (0.42 insects/m^2/min.) followed by Nagrota (0.37 insects/m^2/min.) of foraging intensity was observed. Studies are in agreement to the records by Das and Choudhary (1958) and Mann and Dhooria (1994) who also have suggested comparatively more visitors in morning hours.

Data when pooled, the foraging intensity of Syrphid fly was found to be the highest compared to other insects; Sulah (1.50 insects/m^2/min.) followed by Saliana (1.33 insects/m^2/min.), Nagrota (1.17 insects/m^2/min.) and minimum at Palampur (0.50 insects/m^2/min.) and our results are in close conformity to Srivastava et al. (2017). Foraging intensity of *Apis mellifera* was observed comparatively higher at Sulah (1.25 insects/m^2/min.) followed by Nagrota (0.50 insects/m^2/min.). *A. cerana* was prominent in terms of foraging intensity at Nagrota (0.67 insects/m^2/min.) followed by Sulah (0.58 insects/m^2/min.) and Palampur (0.33 insects/m^2/min.) however *A. dorsata* was recorded abundant at Nagrota (0.75 insects/m^2/min.) followed by Sulah (0.42 insects/m^2/min.) as shown in Fig. 4.1. Our findings are in proximity to records of interaction on location and insect visitors on apple crop Raj et al. (2012), Mattu and Bhagat (2015) and Mushtaq et al. (2017).

The relative abundance was in order of honeybees 43.17 % (*A. mellifera* 17.71 %, *A. cerana* 14.76 %, *A. dorsata* 10.70 %), Syrphid fly (41.69 %) while *Megachile* sp. (1.47%) and *Polistes* sp. (1.47%) were also seen in very low percentage (Fig. 4.2).

Table 4.2 Population of insect visitors (insects/m^2/min.) and their abundance during early bloom in litchi, *Litchi chinensis* Sonn. at different locations

Insects	1000-1100 hours					Relative Abundance (%)	1400-1500 hours					Relative Abundance (%)	Pooled					Relative Abundance (%)
	Saliana	Palampur	Sulah	Nagrota	Mean		Saliana	Palampur	Sulah	Nagrota	Mean		Saliana	Palampur	Sulah	Nagrota	Mean	
Apis mellifera	0.33 (1.14)	0.00 (1.00)	1.17 (1.47)	0.50 (1.23)	0.50 (1.21)	15.15	0.00 (1.00)	0.00 (1.00)	1.33 (1.50)	0.50 (1.21)	0.46 (1.18)	20.90	0.17 (1.08)	0.00 (1.00)	1.25 (1.49)	0.50 (1.22)	0.48 (1.20)	17.71
Apis cerana	0.00 (1.00)	0.67 (1.24)	0.50 (1.19)	0.67 (1.28)	0.46 (1.18)	13.93	0.00 (1.00)	0.00 (1.00)	0.67 (1.27)	0.67 (1.29)	0.33 (1.14)	15.00	0.00 (1.00)	0.33 (1.14)	0.58 (1.25)	0.67 (1.29)	0.40 (1.17)	14.76
Apis dorsata	0.00 (1.00)	0.00 (1.00)	0.50 (1.21)	1.17 (1.46)	0.42 (1.17)	12.72	0.00 (1.00)	0.00 (1.00)	0.33 (1.15)	0.33 (1.14)	0.17 (1.07)	7.72	0.00 (1.00)	0.00 (1.00)	0.42 (1.19)	0.75 (1.31)	0.29 (1.12)	10.70
Syrphid fly	2.67 (1.91)	0.50 (1.19)	1.50 (1.57)	0.67 (1.27)	1.33 (1.49)	40.30	0.00 (1.00)	0.50 (1.21)	1.50 (1.56)	1.67 (1.63)	0.92 (1.35)	41.81	1.33 (1.53)	0.50 (1.21)	1.50 (1.57)	1.17 (1.46)	1.13 (1.44)	41.69
Bombus spp.	0.00 (1.00)	0.00 (1.00)	0.33 (1.15)	0.00 (1.00)	0.08 (1.04)	2.42	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.33 (1.14)	0.08 (1.04)	3.63	0.00 (1.00)	0.00 (1.00)	0.17 (1.08)	0.17 (1.08)	0.08 (1.04)	2.95
Megachile spp.	0.00 (1.00)	0.00 (1.00)	0.17 (1.08)	0.00 (1.00)	0.04 (1.02)	1.21	0.00 (1.00)	0.17 (1.08)	0.00 (1.00)	0.00 (1.00)	0.04 (1.02)	1.81	0.00 (1.00)	0.08 (1.04)	0.08 (1.04)	0.00 (1.00)	0.04 (1.02)	1.47
Polistes spp.	0.00 (1.00)	0.00 (1.00)	0.17 (1.08)	0.00 (1.00)	0.04 (1.02)	1.21	0.00 (1.00)	0.00 (1.00)	0.17 (1.02)	0.00 (1.00)	0.04 (1.02)	1.81	0.00 (1.00)	0.00 (1.00)	0.17 (1.08)	0.00 (1.00)	0.04 (1.02)	1.47
Pimpla spp.	0.00 (1.00)	0.00 (1.00)	0.17 (1.08)	0.33 (1.14)	0.13 (1.05)	3.93	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00	0.00 (1.00)	0.00 (1.00)	0.08 (1.04)	0.17 (1.08)	0.06 (1.03)	2.21
Lepidoptera	0.50 (1.21)	0.17 (1.08)	0.00 (1.00)	0.17 (1.08)	0.21 (1.09)	6.36	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.17 (1.08)	0.04 (1.02)	1.81	0.25 (1.11)	0.08 (1.04)	0.00 (1.00)	0.17 (1.08)	0.13 (1.06)	4.79
Coleoptera	0.00 (1.00)	0.00 (1.00)	0.33 (1.15)	0.00 (1.00)	0.08 (1.04)	2.42	0.33 (1.14)	0.00 (1.00)	0.17 (1.08)	0.00 (1.00)	0.13 (1.05)	5.90	0.17 (1.08)	0.00 (1.00)	0.25 (1.11)	0.00 (1.00)	0.10 (1.05)	3.69
Mean	0.35 (1.00)	0.13 (1.05)	0.48 (1.20)	0.35 (1.14)	0.33 (1.13)		0.03 (1.01)	0.07 (1.03)	0.42 (1.16)	0.37 (1.15)	0.22 (1.08)		0.19 (1.08)	0.10 (1.04)	0.45 (1.19)	0.36 (1.15)		

Each value represents the mean value of 3 replicates.

Figures in parentheses are the means of $\sqrt{n+1}$ transformation.

CD (p=0.05) for:	1000-1100 hours	1400-1500 hours	Pooled
Location	0.08	0.07	0.06
Insect pollinator	0.13	0.11	0.09
Location × Insect pollinator	0.26	0.21	0.18
C.V.	13.96	11.87	10.05

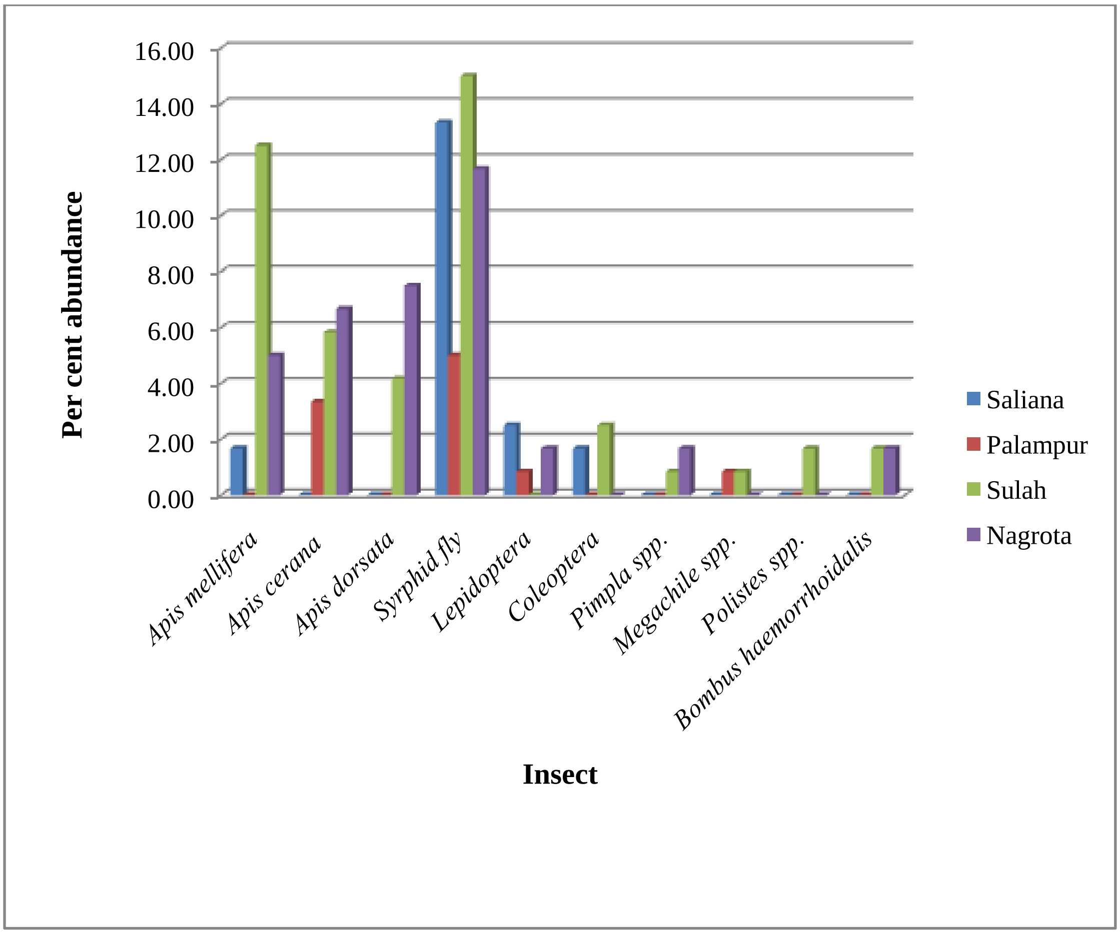


Fig. 4.1 Abundance of insects during early bloom on *Litchi chinensis* at different locations

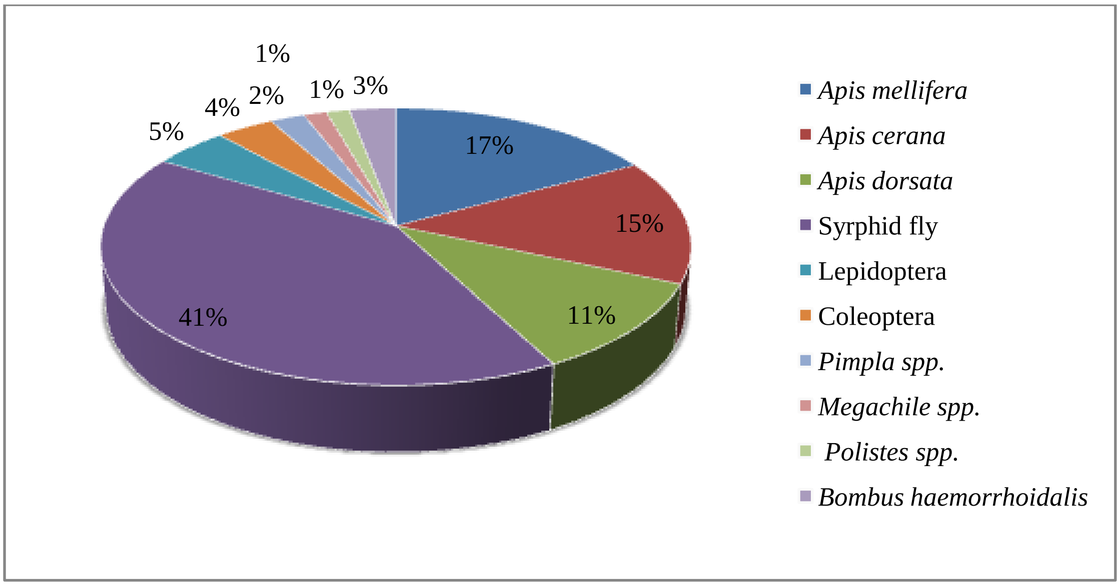


Fig. 4.2 Abundance of insects during early bloom on *Litchi chinensis*

The results are in accordance to Dubey et al. (2020) who have studied the diversity of insect visitors in litchi and reported honeybees as the major pollinators. Srivastava et al. (2017) conducted studies in Bihar on litchi and revealed that Syrphid flies were the second most predominant visitor and support our findings.

(b) Peak bloom

The mean foraging intensity during morning was maximum at Palampur (0.71 insects/m^2/min.) and minimum at Saliana (0.54 insects/m^2/min.) while in afternoon it was found maximum at Nagrota (0.69 insects/m^2/min.) and least at Saliana (0.35 insects/m^2/min.) as per table 4.3. A significant interaction between location and insect pollinators was recorded as was also reported by Mattu and Bhagat 2016. Syrphid fly had maximum foraging intensity at Palampur (2.67 insects/m^2/min.) followed by Sulah (2.42 insects/m^2/min.) and Nagrota (1.58 insects/m^2/min.) as per Fig. 4.3. Among honeybees, *A. cerana* had maximum foraging intensity at Saliana (1.17 insects/m^2/min.) followed by Nagrota (1.06 insects/m^2/min.) and Palampur (0.92 insects/m^2/min). *A. mellifera* was present in a large population at Nagrota (1.08 insects/m^2/min.) while *A. cerana* was recorded abundant at Saliana (1.17 insects/m^2/min.). *A. dorsata* was observed abundant at Nagrota (0.33 insects/m^2/min.), Palampur (0.33 insects/m^2/min.) and Saliana (0.33 insects/m^2/min.) which were at par with each other. As it can be clearly seen in Fig. 4.4, per cent abundance of Syrphid flies (44.06 %) was higher subsequently followed by honeybees (41.24 %). Similar trend was also reported by Mushtaq et al. (2017) and Usha et al. (2009).

4.2.2 Foraging rate

Foraging rate of honeybee species; as number of flowers visited by each honeybee per minute was assessed.

(a) Morning hours

Average foraging rate of four locations as in table 4.4 revealed that *A. cerana* registered maximum visitation (10.19 flowers/min.) followed by *A. dorsata* (8.46 flowers/min.) and *A. mellifera* (7.40 flowers/min.) and is also apparent in Fig. 4.5. Similar results were also reported by Das et al. (2019) for foraging rates of *A. cerana indica* (12.26 flowers/minute), *A. mellifera* (11.12 flowers/min.) and *A. dorsata* (10.54 flowers/min.) in litchi crop while Chaudhary and Singh (2007) in coriander.

Table 4.3 Population of insect visitors (insects/m^2/min.) and their abundance during peak bloom in litchi, *Litchi chinensis* at different locations

Insects	1000-1100 hours					Relative Abundance (%)	1400-1500 hours					Relative Abundance (%)	Pooled					Relative Abundance (%)
	Saliana	Palampur	Sulah	Nagrota	Mean		Saliana	Palampur	Sulah	Nagrota	Mean		Saliana	Palampur	Sulah	Nagrota	Mean	
Apis mellifera	0.83 (1.35)	0.17 (1.08)	1.00 (1.41)	0.67 (1.47)	0.67 (1.33)	12.88	0.17 (1.08)	0.33 (1.15)	0.83 (1.34)	1.50 (1.56)	0.71 (1.28)	17.40	0.50 (1.23)	0.25 (1.11)	0.92 (1.38)	1.08 (1.52)	0.69 (1.31)	14.90
Apis cerana	1.67 (1.62)	1.00 (1.39)	0.67 (1.29)	1.11 (1.33)	1.11 (1.41)	21.34	0.67 (1.27)	0.83 (1.33)	0.50 (1.23)	1.00 (1.41)	0.75 (1.31)	18.38	1.17 (1.46)	0.92 (1.38)	0.58 (1.26)	1.06 (1.37)	0.93 (1.37)	20.08
Apis dorsata	0.33 (1.15)	0.17 (1.08)	0.00 (1.00)	0.17 (1.41)	0.17 (1.16)	3.26	0.33 (1.15)	0.50 (1.21)	0.33 (1.15)	0.50 (1.21)	0.42 (1.18)	10.29	0.33 (1.15)	0.33 (1.15)	0.17 (1.08)	0.33 (1.32)	0.29 (1.17)	6.26
Syrphid fly	1.33 (1.53)	2.83 (1.95)	1.83 (1.68)	2.00 (1.41)	2.00 (1.64)	38.46	1.67 (1.62)	2.50 (1.86)	3.00 (1.98)	0.17 (1.43)	2.08 (1.72)	50.98	1.50 (1.58)	2.67 (1.91)	2.42 (1.85)	1.58 (1.43)	2.04 (1.69)	44.06
Bombus spp.	0.00 (1.00)	0.00 (1.00)	0.17 (1.08)	0.06 (1.00)	0.06 (1.02)	1.15	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00	0.00 (1.00)	0.00 (1.00)	0.08 (1.04)	0.03 (1.00)	0.03 (1.01)	0.64
Megachile spp.	0.00 (1.00)	0.00 (1.00)	0.17 (1.08)	0.06 (1.00)	0.06 (1.02)	1.15	0.00 (1.00)	000 (1.00)	0.00 (1.00)	0.33 (1.15)	0.08 (1.04)	1.96	0.00 (1.00)	0.00 (1.00)	0.08 (1.04)	0.19 (1.08)	0.07 (1.03)	1.51
Others	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.14)	0.00 (1.04)	0.00	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	1.00 (1.14)	0.25 (1.04)	0.05	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.50 (1.15)	0.13 (1.04)	2.80
Coleoptera	0.17 (1.08)	1.50 (1.53)	1.67 (1.55)	1.11 (1.00)	1.11 (1.29)	21.34	0.00 (1.00)	0.00 (1.00)	0.17 (1.08)	0.00 (1.00)	0.04 (1.02)	0.98	0.08 (1.04)	0.75 (1.30)	0.92 (1.34)	0.56 (1.00)	0.58 (1.17)	12.52
Mean	0.54 (1.22)	0.71 (1.25)	0.69 (1.26)	0.65 (1.22)	0.65 (1.23)		0.35 (1.14)	0.52 (1.19)	0.60 (1.22)	0.69 (1.24)	0.54 (1.19)		0.45 (1.18)	0.61 (1.23)	0.65 (1.25)	0.67 (1.23)		

Each value represents the mean value of 3 replicates.

Figures in parentheses are the means of $\sqrt{n+1}$ transformation.

CD (p=0.05) for:	1000-1100 hours	1400-1500 hours	Pooled
Location	NS	NS	NS
Insect pollinator	0.15.	0.15	0.12
Location × Insect pollinator	0.31	NS	0.24
C.V.	15.25	14.95	11.91

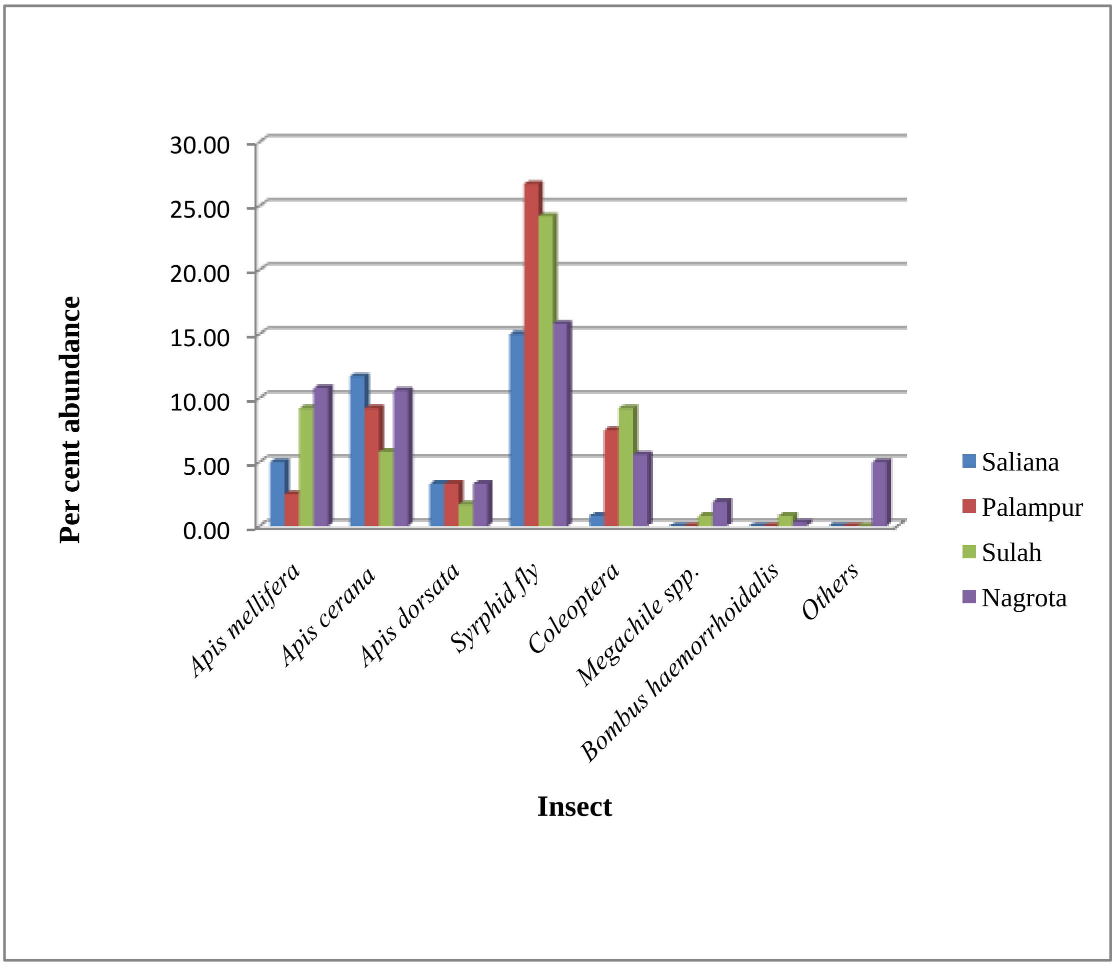


Fig. 4.3 Abundance of insects during peak bloom on *Litchi chinensis* at different locations

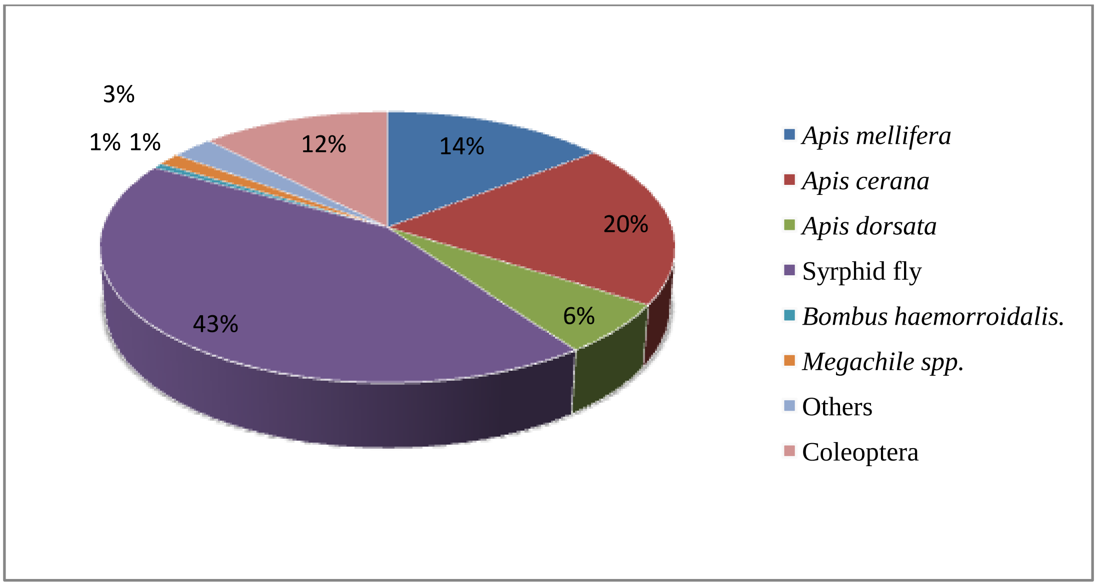


Fig. 4.4 Abundance of insects during peak bloom on *Litchi chinensis*

Table 4.4 Mean number of flowers visited by honeybee species, *Apis* spp. at different locations in Kangra district of Himachal Pradesh on litchi, *Litchi chinensis*

Location / Honeybee	Number of flowers visited by honeybee/minute									
	Morning					Afternoon				
	Saliana	Palampur	Sulah	Nagrota	Mean	Saliana	Palampur	Sulah	Nagrota	Mean
Apis mellifera	5.50 (2.54)	4.42 (2.31)	10.50 (3.39)	9.17 (3.18)	7.40 (2.86)	10.00 (3.30)	8.50 (3.07)	10.17 (3.33)	11.50 (3.53)	10.04 (3.31)
Apis cerana	10.00 (3.31)	11.08 (3.47)	10.00 (3.31)	9.67 (3.26)	10.19 (3.34)	10.92 (3.44)	8.92 (3.14)	8.83 (3.12)	10.00 (3.31)	9.67 (3.26)
Apis dorsata	8.33 (3.03)	9.08 (3.17)	7.92 (2.98)	8.50 (3.09)	8.46 (3.06)	8.08 (3.10)	8.67 (3.10)	8.83 (3.13)	8.57 (3.11)	8.58 (3.09)
Mean	7.94 (2.96)	8.19 (2.98)	9.47 (3.23)	9.11 (3.17)		9.67 (3.25)	8.69 (3.11)	9.28 (3.19)	10.08 (3.32)	

Each value represents the mean value of 3 replicates.

Figures in parentheses are the means of $\sqrt{n+1}$ transformation.

CD (p=0.05) for:

Morning	C.D.(p=0.05)
Insect pollinator	0.20
Location	0.17
Insect pollinator × Location	0.35
C.V.	6.77

Afternoon	C.D.(p=0.05)
Insect pollinator	NS
Location	0.16
Insect pollinator × Location	NS
C.V.	5.98

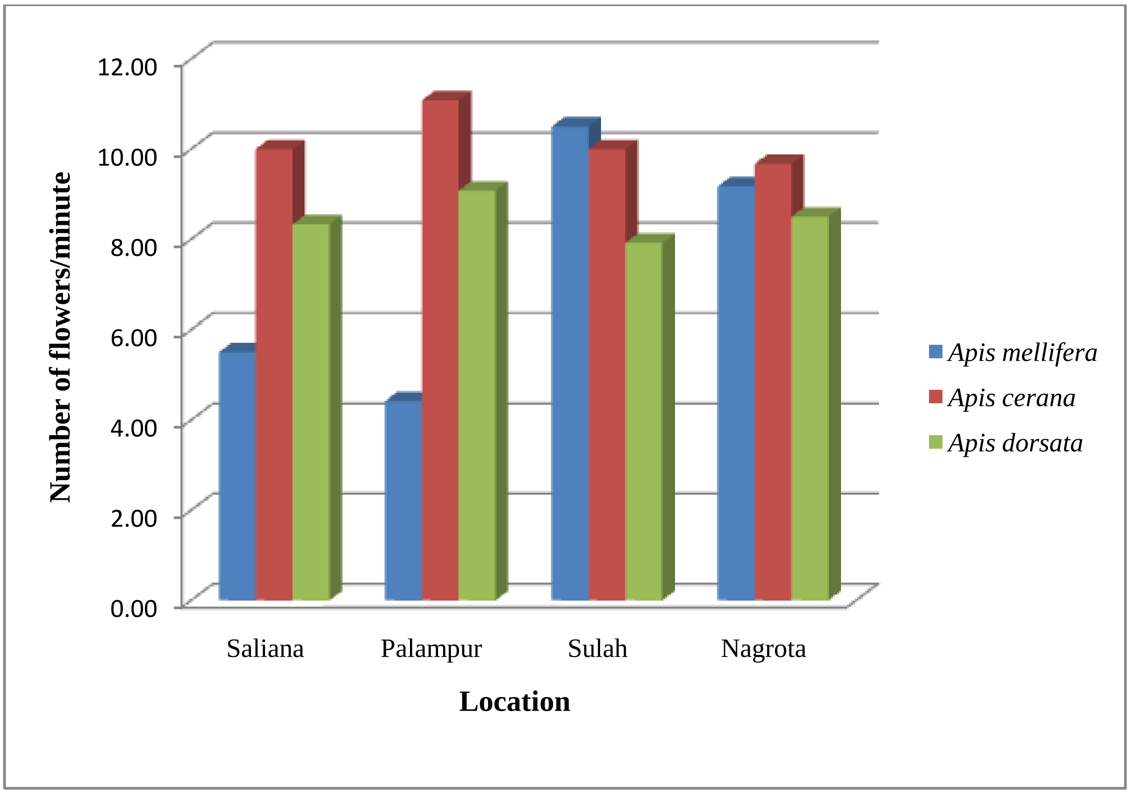


Fig. 4.5 Foraging rate of honeybees on *Litchi chinensis* in morning hours

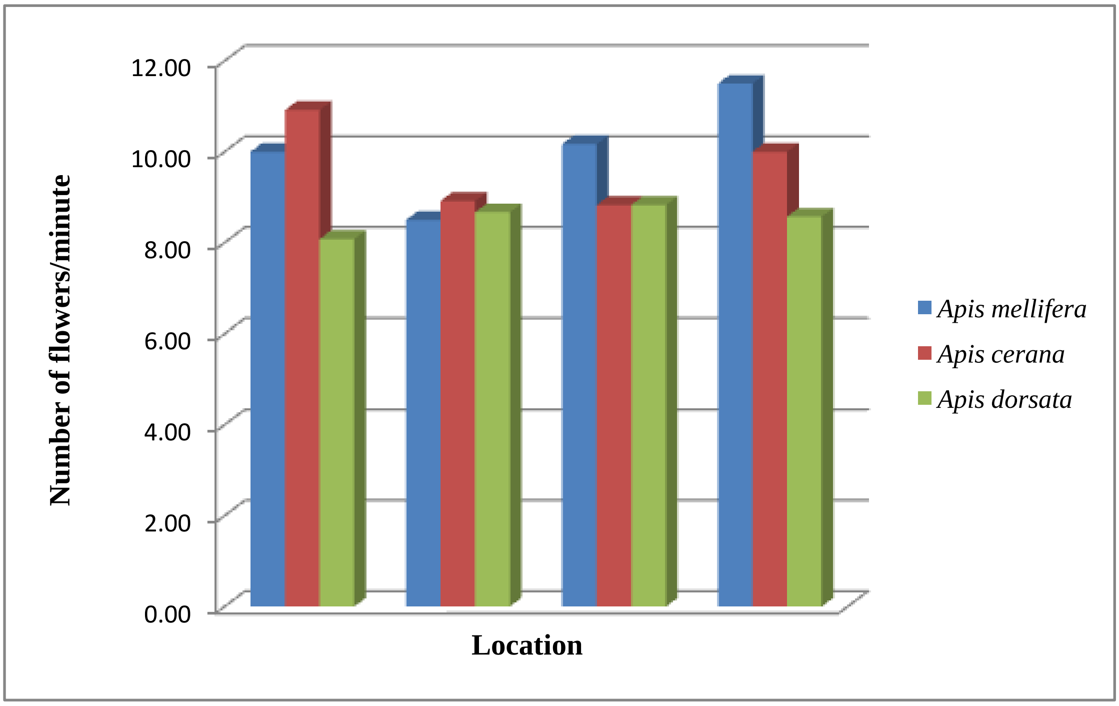


Fig. 4.6 Foraging rate of honeybees on *Litchi chinensis* in afternoon hours

(b) Afternoon hours

It is evident from the table 4.4 average foraging rate at different locations in afternoon hours *i.e.* 1400-1500 hours was found maximum in case of *A. mellifera* (10.04 flowers/minute) followed by *A. cerana* (9.67 flowers/minute) and *A. dorsata* (8.58 flowers/minute) and is also reproduced in Fig. 4.6. The visitation among frequencies calculated as foraging rate among different species was found to be statistically at par with each other. In a study conducted by Mishra and Kumar (2018) in litchi a similar trend *A. mellifera* (11.61 flowers/minute) followed by *A. dorsata* (10.41 flowers/minute) has been reported.

4.2.3 Foraging speed

Foraging speed of each visiting honeybee species was recorded as the time (in seconds) spent by them on a single flower

(a) Morning hours

It is evident from the table 4.5 that the average foraging speed at different locations in morning was found maximum in *A. dorsata* (7.55 seconds) on litchi followed by *A. cerana* (6.11 seconds) and *A. mellifera* (5.56 seconds) and the data is also reproduced in Fig. 4.7. The time spent by honeybees (in seconds) was found to be statistically at par with each other. Similar results on honeybee foraging speed with slight difference was also documented by Mishra and Kumar (2018) in litchi. They recorded the maximum foraging speed in *A. dorsata* (10.28 sec.) and minimum in case of *A. florea* being 6.97 seconds. The difference in the present studies where observation was of peak bloom, it may be due to the different climatic conditions and the density of the inflorescence at the time of observation in both test conditions.

(b) Afternoon hours

The foraging speed assessed at four different locations in Shivalik region of Himachal Pradesh was statistically significant as table 4.5 reveals that *A. cerana* spent maximum time of 7.34 seconds on flowers followed by *A. dorsata* (7.19 sec.) while *A. mellifera* was very agile and spent 6.41 seconds, the trend is also apparent in Fig. 4.8. On the contrary, there had been some mismatch in figures reported as *A. dorsata* (4.64 sec.) by Das et al. (2019) and Neupane (2001) from Nepal for honeybees 2.9±1.0 sec./litchi. It may be attributed to the blooming period, prevailing climatic conditions and time of observation in both test conditions.

Table 4.5 Time spent (seconds) by honeybee species, *Apis* spp. at different locations in Kangra district of Himachal Pradesh on litchi, *Litchi chinensis*

Location / Honeybee	Time spent by honeybee/flower (seconds)									
	Morning					Afternoon				
	Saliana	Palampur	Sulah	Nagrota	Mean	Saliana	Palampur	Sulah	Nagrota	Mean
Apis mellifera	4.80 (2.38)	6.48 (2.73)	5.39 (2.51)	5.56 (2.54)	5.56 (2.54)	4.94 (2.42)	8.84 (3.10)	4.51 (2.33)	7.35 (2.88)	6.41 (2.69)
Apis cerana	6.20 (2.66)	7.45 (2.89)	4.37 (2.30)	6.40 (2.70)	6.11 (2.63)	8.93 (3.14)	9.13 (3.17)	5.69 (2.58)	5.60 (2.55)	7.34 (2.86)
Apis dorsata	7.17 (2.85)	8.39 (3.01)	6.04 (2.65)	8.60 (3.09)	7.55 (2.90)	5.12 (2.46)	7.59 (2.92)	8.83 (3.08)	7.23 (2.86)	7.19 (2.83)
Mean	6.06 (2.63)	7.44 (2.88)	5.27 (2.48)	6.86 (2.78)		6.33 (2.68)	8.52 (3.07)	6.34 (2.66)	6.73 (2.76)	

Each value represents the mean value of 3 replicates.

Figures in parentheses are the means of $\sqrt{n+1}$ transformation.

CD (p=0.05) for:

Morning	C.D.(p=0.05)
Insect pollinator	NS
Location	0.29
Insect pollinator × Location	NS
C.V.	12.83

Afternoon	C.D.(p=0.05)
Insect pollinator	NS
Location	NS
Insect pollinator × Location	0.54
C.V.	11.57

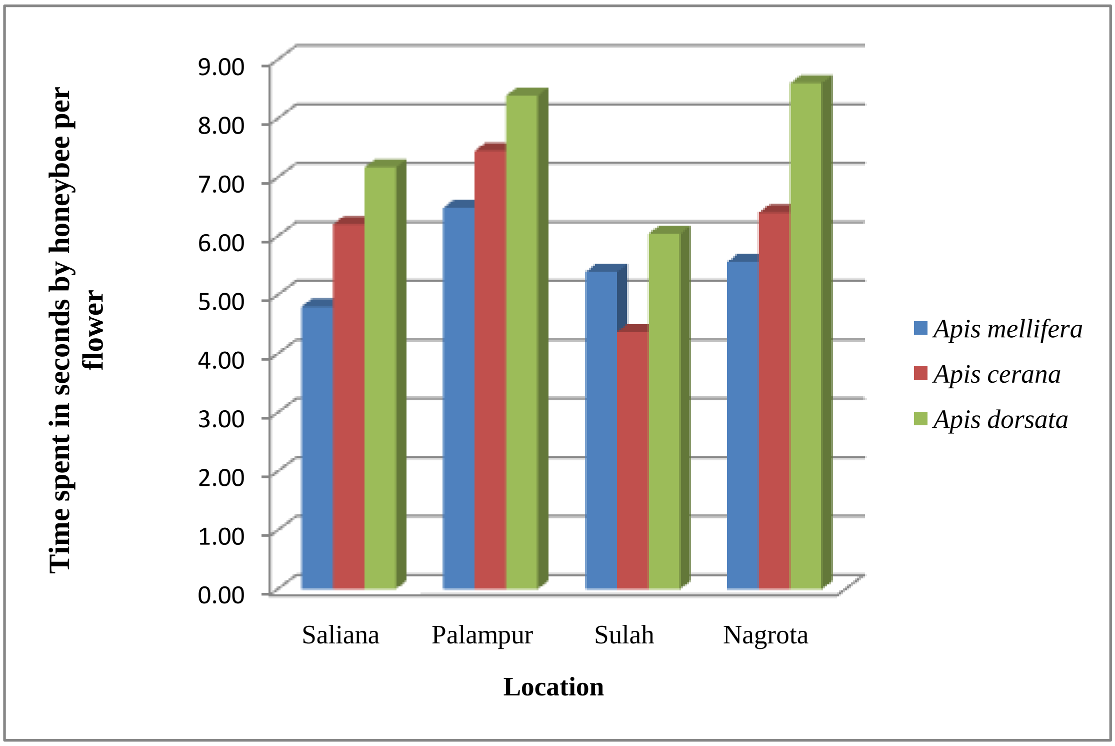


Fig. 4.7 Foraging speed of honeybees on *Litchi chinensis* in morning hours

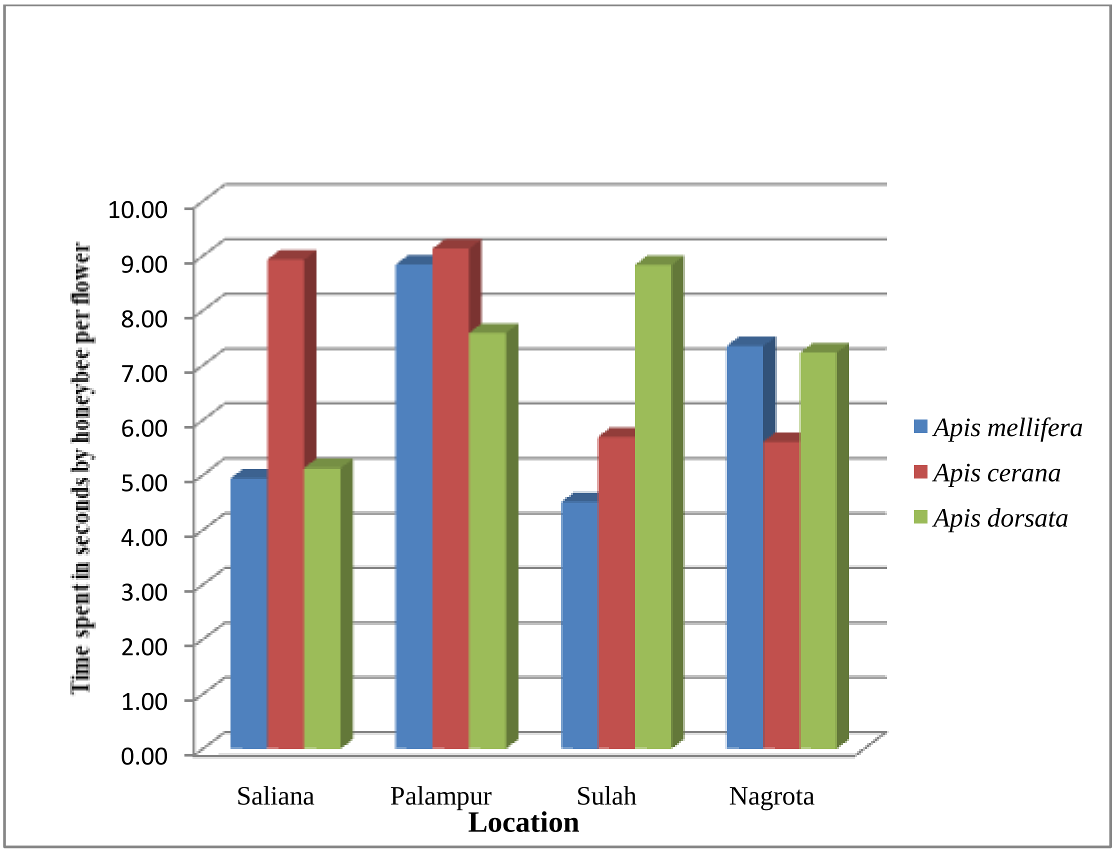


Fig. 4.8 Foraging speed of honeybees on *Litchi chinensis* in afternoon hours

As shown in Fig. 4.7 in early hours of day foraging speed assessed at different locations which was not significant to each other however there was some difference in their speeds. Foraging speed of *A. mellifera* at Palampur (6.48 sec.), Nagrota (5.56 sec.), Sulah (5.39 sec.) and at Saliana (4.80 sec.) while *Apis cerana*, Palampur (7.45 sec.), Nagrota (6.40 sec.), Saliana (6.20 sec.) and at Sulah (4.37 sec.). Foraging speed of *A. dorsata* was maximum at Nagrota (8.60 sec.) followed by Palampur (8.39 sec.), Saliana (7.17 sec.) and Sulah (6.04 sec.). But during afternoon hours (as apparent in the Table 4.4 and in Fig. 4.8), there is significant interaction among honeybees and locations. Foraging speed of *A. mellifera* was significantly high at Palampur (8.84 sec.), *A. cerana* with maximum speed at Palampur (9.13 sec.) and *A. dorsata* with maximum agility at Sulah (8.63 sec.).

4.2.4 Foraging mode

Foraging mode of different honeybee species as the ratio of top foragers and side foragers was worked out.

Foraging mode (as shown in Table 4.6) was the highest of *A. mellifera* (2.33) followed by *A. dorsata* (1.86) and *A. cerana* (1.35). It also indicates that the top forager population among these pollinators was recorded highest for *A. mellifera*, than *A. dorsata* and *A. cerana* (Fig. 4.9). Similar results with higher percentage of *Apis mellifera* as top foragers than *A. cerana* were also reported from Kullu in apple by Mattu and Bhagat (2015). Present findings are also in close conformity with Khamhari (2013).

Table 4.6 Foraging mode of honeybee species on litchi, *Litchi chinensis* Sonn. at different locations in Kangra district

Honeybee species	**Type of Forager**	**Location**								
		Ratio of foragers								
		Saliana		Palampur		Sulah		Nagrota		Mean
Apis mellifera	Top foragers	17.00	5.67	11.00	1.22	12.00	1.50	16.00	4.00	2.33
	Side foragers	3.00		9.00		8.00		4.00		
Apis cerana	Top foragers	9.00	0.82	12.00	1.50	13.00	1.86	12.00	1.50	1.35
	Side foragers	11.00		8.00		7.00		8.00		
Apis dorsata	Top foragers	16.00	4.00	11.00	1.22	15.00	3.00	10.00	1.00	1.86
	Side foragers	4.00		9.00		5.00		10.00		
Mean			3.49		1.31		2.12		2.17	

20 individuals for each honeybee species were observed.

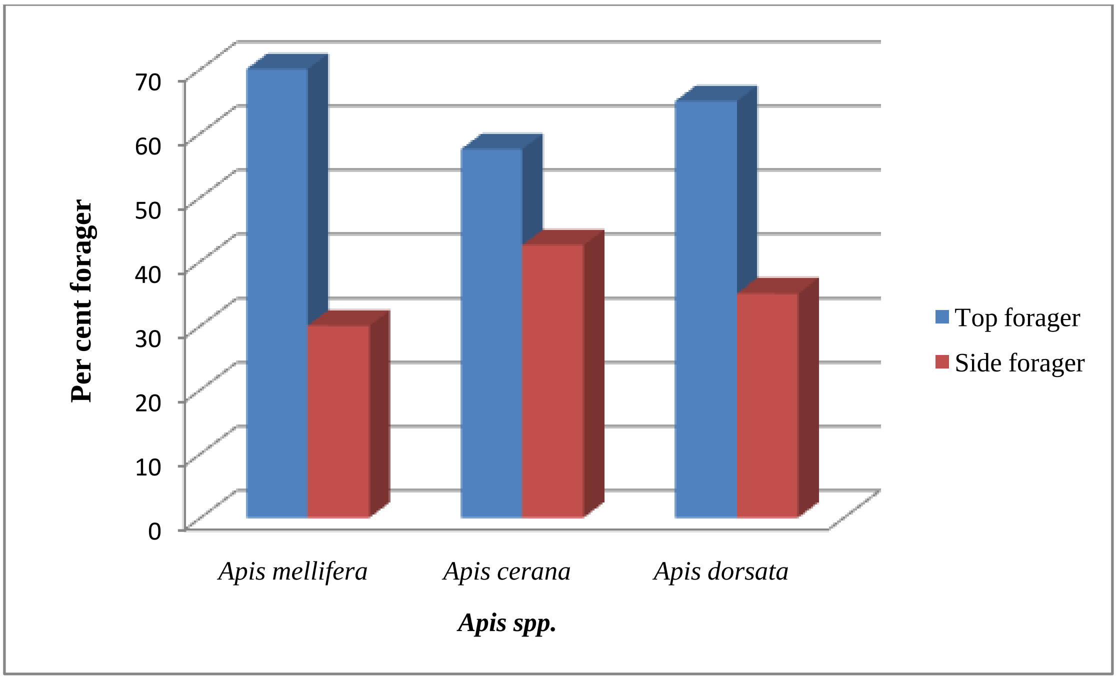


Fig. 4.9 Types of foragers in *Litchi chinensis*

4.2.5 Number of loose pollen grains adhered to the body of honeybee species

(a) Body of honeybees

The data on loose pollen grains indicated that among *Apis* pollinators maximum number of loose pollen grains (4,00,000) were recovered from the body of *Apis dorsata* followed by *Apis mellifera* (3,72,000) and *Apis cerana* (2,64,000) (as shown in Table 4.7). Significant difference was also found among the number of loose pollen grains sticking to the body of three honeybees. Similar trend for the loose pollen stuck to honeybee body is in accordance with Raj et al. (1993); Kitroo and Abrol (1996); Mehta (2009), Khamhari (2013) and Bharti et al. (2015).

(b) Hind legs of honeybees

The data on counts of pollen grains on hind legs showed that among *Apis* pollinators maximum number of pollen grains (3,18,000) were recovered from *A. dorsata* followed by *A. mellifera* (2,86,000) and *A. cerana* (1,88,000). Significant difference was found among the number of pollen grains sticking to the hindlegs of three species of honeybees. Comparing the counts of loose pollen grains; the number of pollen grains sticking to the body was more than on the hind legs (Table 4.7).

Table 4.7 Pollination efficiency index of honeybee species on litchi, *Litchi chinensis* in Himachal Pradesh

Honeybee species	*Abundance	**Foraging rate	Loose pollen grains sticking on the body of bees	Loose pollen grains sticking to pollen pellets on the hind legs	Pollination efficiency (abundance × foraging rate × loose pollen grains)	Log_{10} value of pollination efficiency or P.E.I.	P.E.I. Rank
Apis mellifera	0.58	8.72	3,72,000.00	2,86,000.00	18,78,600.00	6.27	1st
Apis cerana	0.66	9.93	2,64,000.00	1,88,000.00	17,29,200.00	6.24	2nd
Apis dorsata	0.29	8.52	4,00,000.00	3,18,000.00	9,88,320.00	5.99	3rd

Each value represents the mean value of 5 replicates for count of pollen grains on body and hind legs.

*Abundance of honeybee is the mean value of relative abundance in early and peak bloom.

**Foraging rate is the mean value of number of flowers visited by honeybee/minute in morning and afternoon hours.

4.2.6 Pollination efficiency index (P.E.I.) of honeybees on *Litchi chinensis*

Indexing of three species of honeybees foraging on litchi flowers for their pollination efficiency is presented in table 4.7. The results obtained revealed that the P.E.I. of *A. mellifera* (6.27) was the highest compared to *A. cerana* (6.24) and *A. dorsata* (5.99). *A. mellifera* was the most efficient pollinator of litchi which got support from the results of McGregor (1976); Vithanage and Ironside (1986) and Vithanage (1986) and Kumar (2014).

4.3 Diversity of pollinating insects

The results for diversity of guava insect visitors in 2020 are compiled in the table 4.8.

Table 4.8 Diversity of insect visitors of guava in Kangra during 2020

Sr. No.	Insect species	Order	Family	Location
1.	*Apis mellifera*	Hymenoptera	Apidae	Jachh
2.	*Apis cerana indica*	Hymenoptera	Apidae	Palampur
3.	*Apis dorsata*	Hymenoptera	Apidae	Palampur
4.	*Polistes* sp.	Hymenoptera	Vespidae	Jachh
5.	*Eristalis tenax*	Diptera	Syrphidae	Palampur
6.	*Eristalis* sp	Diptera	Syrphidae	Bharwar
7.	*Paragus* sp.	Diptera	Syrphidae	Bharwar
8.	*Episyrphus viridaureus*	Diptera	Syrphidae	Jachh
9.	*Coccinella septempunctata*	Coleoptera	Coccinellidae	Jachh
10.	*Colasposoma lividipes*	Coleoptera	Chrysomelidae	Bharwar
11.	*Colias philodice*	Lepidoptera	Pieridae	Palampur
12.	*Colias crocerus*	Lepidoptera	Pieridae	Bharwar

4.3.1 Relative abundance of insects

i) Foraging intensity and relative abundance of insects in guava

The number of insects visiting on a selected area of the plant in one minute was recorded during morning 1000-1100 hours and afternoon 1400-1500 hours at three locations.

(a) Early bloom

The maximum average foraging intensity was observed at Bharwar (0.83 insects/m^2/min.), followed by Jachh (0.46 insects/m^2/min.) and Palampur (0.25 insects/m^2/min.) in morning hours, as apparent in the table 4.9. During afternoon hours a similar trend with maximum value at Bharwar (0.67insects/m^2/min.) followed by Palampur (0.38 insects/m^2/min.) and Jachh (0.21 insects/m^2/min.) was recorded table 4.9. When data was pooled the trend showed maximum value once again at Bharwar (0.47 insects/m^2/min) followed by Jachh (0.33 insects/m^2/min.) and Palampur (0.31 insects/m^2/min.) and is evident in Fig. 4.10). However there is no significant interaction between time, three selected locations and pollinators.

Honeybee species; *A. cerana, A. mellifera* and *A. dorsata* were recorded with maximum abundance of 50.65 per cent whereas Syrphid flies as 29.75 per cent. *A. dorsata* (26.80 %) was, however, predominant pollinator among *Apis* pollinators (Fig. 4.11). Our results get conformity from studies by Mann and Dhooria (1994) who also have reported *A. dorsata* as the most dominant visitor in guava.

(b) Peak bloom

The data presented in table 4.10 revealed that the mean foraging intensity of guava insect visitors at1000-1100 hours and 1400-1500 hours had no significant interaction. It was maximum at Jachh followed by Bharwar and Palampur. It is also evident from Fig. 4.12 that the trend showed highest value again at Jachh (0.96) followed by Bharwar (0.88 insects/m^2/min.) and Palampur (0.73 insects/m^2/min.).

Relative abundance in morning and afternoon data showed that *A. cerana* (22.80 %) was the most abundant pollinator followed by *A. dorsata* (22.05 %) and Syrphid flies (21.92 %) and has also been shown in Fig. 4.13. However, Castro and Araujo (1988) from Brazil reported *A. mellifera* as the most abundant visitor on guava blooms. This deviation may be due to different agro-climatic conditions and abundance of some species in that locality, as a number of feral colonies of *A. cerana* were there in test locations of present study and in Brazil there may be absence of *A. cerana*.

Table 4.9 **Population of insect visitors (insects/m^2/min.) and their abundance during early bloom in guava, *Psidium guajava* L. at different locations**

Insects	1000-1100 hours				Relative Abundance (%)	1400-1500 hours				Relative Abundance (%)	Pooled				Relative Abundance (%)
	Jachh	Palampur	Bharwar	Mean		Jachh	Palampur	Bharwar	Mean		Jachh	Palampur	Bharwar	Mean	
Apis mellifera	0.00 (1.00)	0.33 (1.14)	0.67 (1.28)	0.33 (1.14)	8.08	0.33 (1.14)	0.00 (1.00)	0.33 (1.14)	0.22 (1.09)	6.54	0.17 (1.00)	0.17 (1.14)	0.50 (1.28)	0.28 (1.14)	7.50
Apis cerana	0.67 (1.00)	0.33 (1.14)	1.33 (1.49)	0.78 (1.21)	19.11	0.33 (1.14)	0.00 (1.00)	1.00 (1.38)	0.44 (1.17)	13.09	0.50 (1.00)	0.17 (1.00)	1.17 (1.38)	0.61 (1.13)	16.35
Apis dorsata	1.00 (1.28)	0.00 (1.00)	1.33 (1.52)	0.78 (1.27)	19.11	1.00 (1.38)	1.67 (1.63)	1.00 (1.38)	1.22 (1.46)	36.30	1.00 (1.41)	0.83 (1.41)	1.17 (1.41)	1.00 (1.41)	26.80
Syrphid fly	0.33 (1.41)	1.00 (1.38)	2.00 (1.72)	1.11 (1.50)	27.20	0.00 (1.00)	0.67 (1.28)	2.67 (1.90)	1.11 (1.39)	33.03	0.17 (1.28)	0.83 (1.41)	2.33 (1.82)	1.11 (1.50)	29.75
Lepidoptera	0.67 (1.14)	0.33 (1.14)	0.00 (1.00)	0.33 (1.09)	8.08	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00	0.33 (1.00)	0.17 (1.00)	0.00 (1.00)	0.17 (1.00)	4.55
Coleoptera	0.33 (1.28)	0.00 (1.00)	0.67 (1.28)	0.33 (1.18)	8.08	0.00 (1.00)	0.33 (1.14)	0.33 (1.14)	0.22 (1.09)	6.54	0.17 (1.00)	0.17 (1.00)	0.50 (1.14)	0.28 (1.05)	7.50
Polistes spp.	0.33 (1.14)	0.00 (1.00)	0.33 (1.14)	0.22 (1.09)	5.39	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00	0.17 (1.00)	0.00 (1.00)	0.17 (1.00)	0.11 (1.00)	2.94
Others	0.33 (1.14)	0.00 (1.00)	0.33 (1.14)	0.22 (1.09)	5.39	0.00 (1.00)	0.33 (1.14)	0.00 (1.00)	0.11 (1.05)	3.27	0.17 (1.00)	0.17 (1.00)	0.17 (1.00)	0.17 (1.00)	4.55
Mean	0.46 (1.17)	0.25 (1.10)	0.83 (1.32)	0.51 (1.20)		0.21 (1.08)	038 (1.15)	0.67 (1.24)	0.42 (1.16)		0.33 (1.09)	0.31 (1.12)	0.47 (1.25)		

Each value represents the mean value of 3 replicates.

Figures in parentheses are the means of $\sqrt{n+1}$ transformation.

CD (p=0.05) for:	1000-1100 hours	1400-1500 hours	Pooled
Location	0.13	0.12	0.07
Insect pollinator	0.20	0.19	0.12
Location × Insect pollinator	NS	0.33	0.21
C.V.	17.87	17.01	10.88

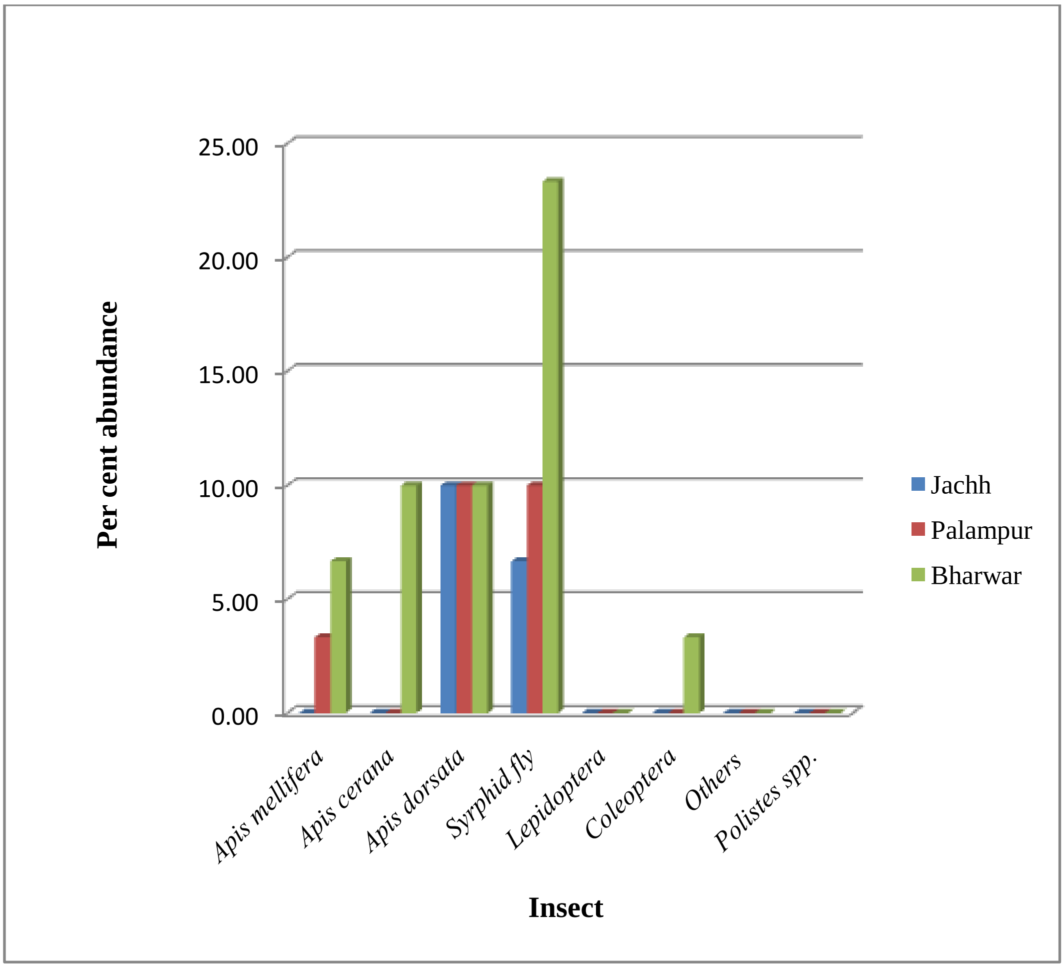


Fig. 4.10 Abundance of insects at early bloom on *Psidium guajava* at different locations

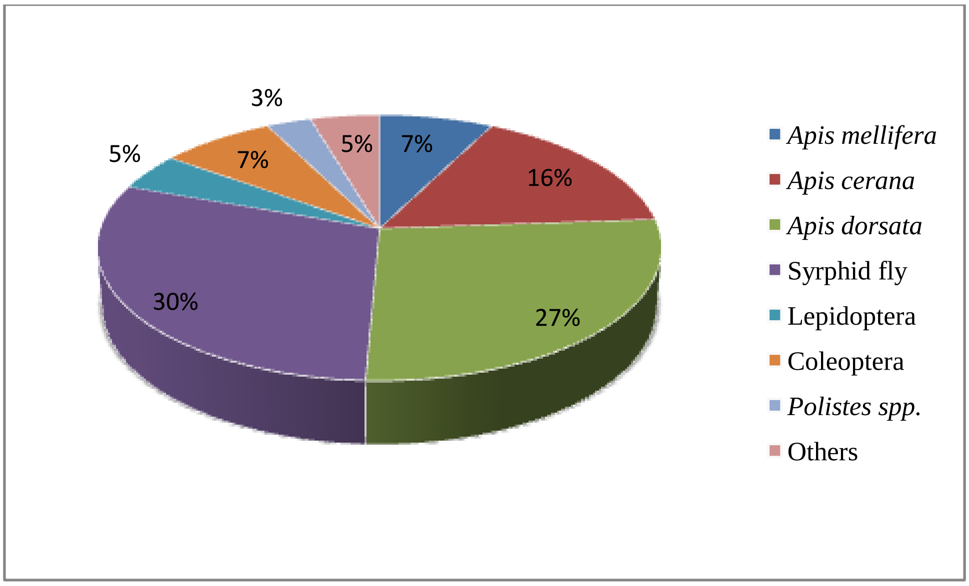


Fig. 4.11 Abundance of insects at early bloom on *Psidium guajava*

Table 4.10 **Population of insect visitors (insects/m^2/min.) and their abundance during peak bloom in guava, *Psidium guajava* at different locations**

Insects	1000-1100 hours				Relative Abundance (%)	1400-1500 hours				Relative Abundance (%)	Pooled				Relative Abundance (%)
	Jachh	Palampur	Bharwar	Mean		Jachh	Palampur	Bharwar	Mean		Jachh	Palampur	Bharwar	Mean	
Apis mellifera	1.00 (1.38)	1.67 (1.63)	2.00 (1.73)	1.56 (1.58)	18.75	0.67 (1.28)	0.33 (1.14)	0.50 (1.14)	0.50 (1.18)	9.32	0.83 (1.28)	1.00 (1.41)	1.25 (1.41)	1.03 (1.37)	15.05
Apis cerana	1.33 (1.52)	1.33 (1.52)	1.67 (1.63)	1.44 (1.56)	17.30	2.00 (1.72)	1.33 (1.52)	1.67 (1.41)	1.67 (1.55)	31.15	1.67 (1.52)	1.33 (1.41)	1.67 (1.41)	1.56 (1.45)	22.80
Apis dorsata	2.00 (1.72)	1.67 (1.63)	1.33 (1.52)	1.67 (1.62)	20.07	1.00 (1.38)	1.67 (1.63)	1.33 (1.28)	1.33 (1.43)	24.81	1.50 (1.49)	1.67 (1.52)	1.33 (1.41)	1.50 (1.47)	22.05
Syrphid fly	2.67 (1.88)	2.33 (1.81)	2.00 (1.72)	2.33 (1.80)	28.00	1.67 (1.58)	1.00 (1.38)	1.33 (1.79)	1.33 (1.59)	24.81	2.17 (1.72)	1.67 (1.73)	1.67 (1.79)	1.83 (1.75)	21.92
Lepidoptera	0.67 (1.28)	0.00 (1.00)	0.00 (1.00)	0.22 (1.09)	2.64	0.67 (1.28)	0.00 (1.00)	0.33 (1.00)	0.33 (1.09)	6.15	0.67 (1.28)	0.00 (1.00)	0.17 (1.00)	0.28 (1.09)	4.09
Coleoptera	0.33 (1.14)	0.00 (1.00)	0.33 (1.14)	0.22 (1.09)	2.64	0.00 (1.00)	0.00 (1.00)	0.00 (1.28)	0.00 (1.09)	0.00	0.17 (1.00)	0.00 (1.00)	0.17 (1.14)	0.11 (1.05)	1.60
Polistes spp.	0.33 (1.14)	0.00 (1.00)	0.67 (1.28)	0.33 (1.14)	3.96	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00	0.17 (1.00)	0.00 (1.00)	0.33 (1.00)	0.17 (1.00)	2.48
Others	0.67 (1.28)	0.33 (1.14)	0.67 (1.28)	0.56 (1.23)	6.73	0.33 (1.14)	0.00 (1.00)	0.17 (1.00)	0.17 (1.05)	3.17	0.50 (1.14)	0.17 (1.00)	0.42 (1.00)	0.36 (1.05)	5.26
Mean	1.13 (1.42)	0.92 (1.34)	1.08 (1.41)	1.04 (1.39)		0.79 (1.30)	0.54 (1.21)	0.67 (1.24)	0.67 (1.25)		0.96 (1.30)	0.73 (1.26)	0.88 (1.27)		

Each value represents the mean value of 3 replicates.

Figures in parentheses are the means of $\sqrt{n+1}$ transformation.

CD (p=0.05) for:	1000-1100 hours	1400-1500 hours	Pooled
Location	NS	NS	NS
Insect pollinator	0.21	0.21	0.16
Location × Insect pollinator	NS	NS	NS
C.V.	16.00	17.75	13.50

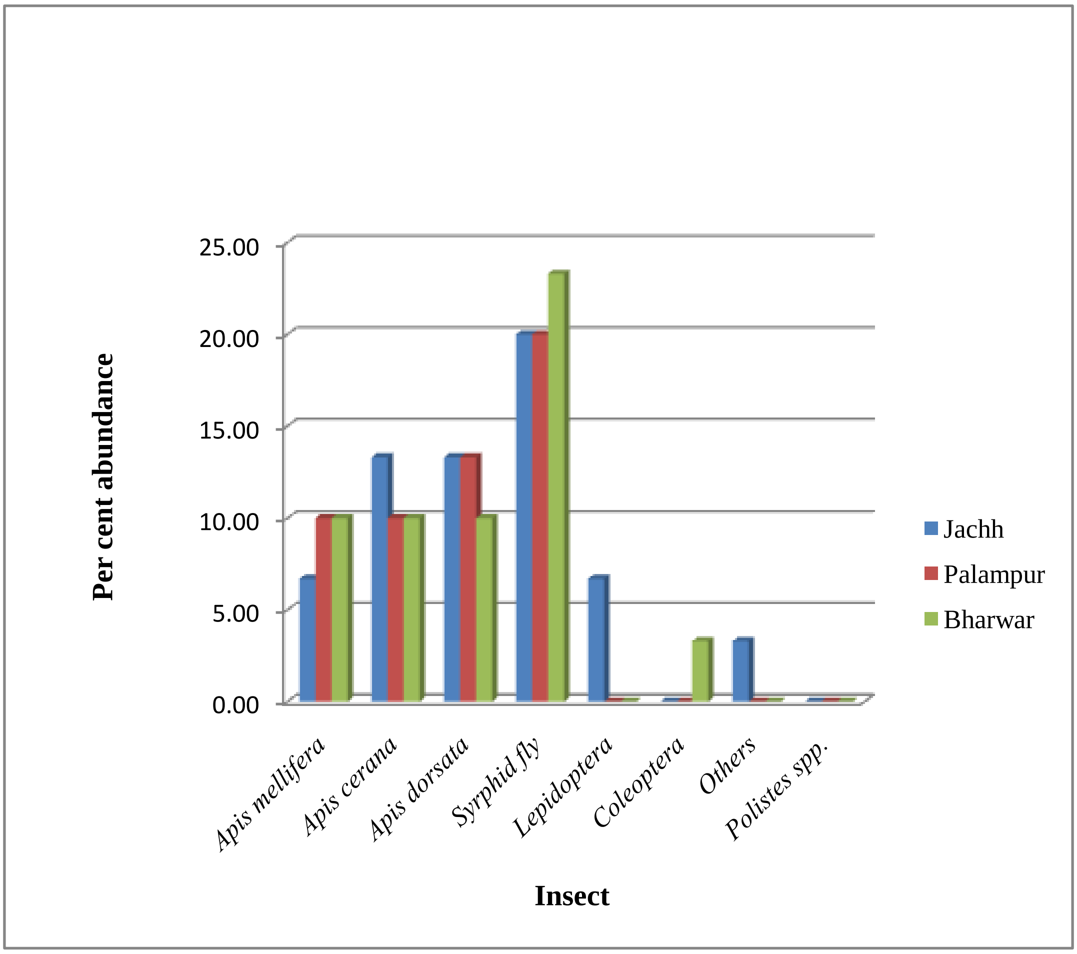


Fig. 4.12 Abundance of insects during peak bloom on *Psidium guajava* at different locations

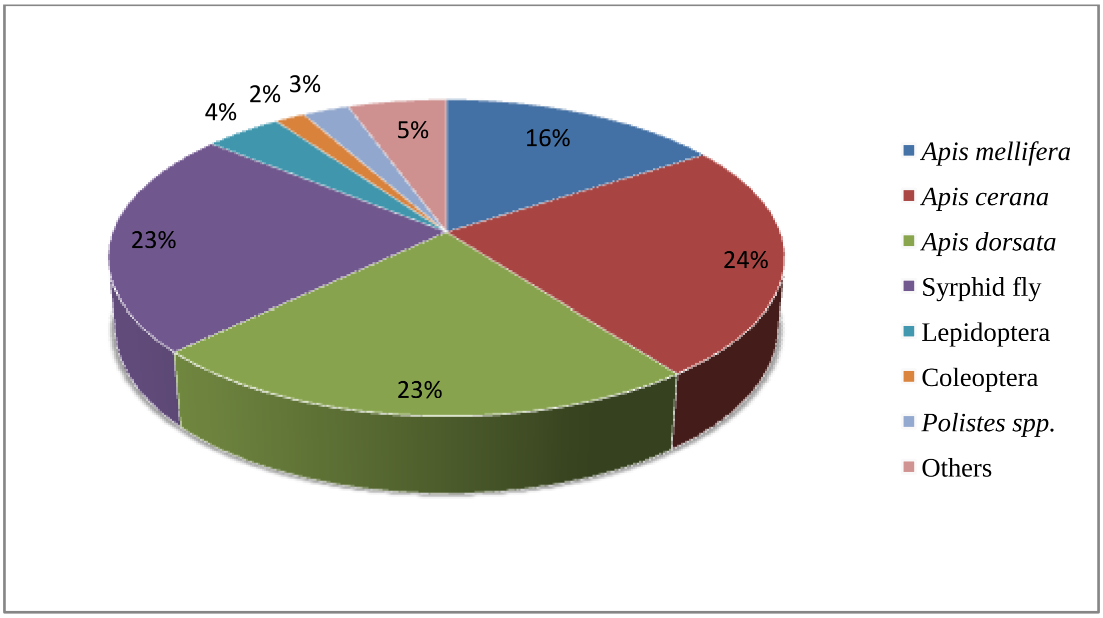


Fig. 4.13 Abundance of insects during peak bloom on *Psidium guajava*

4.3.2 Foraging rate

(a) Morning hours

As presented in table 4.11, the mean foraging rate of honeybees at three different locations during 1000-1100 hours was found significantly higher in case of *A. cerana* (8.06 flowers/min.) followed by *A. mellifera* (6.72 flowers/min.) and *A. dorsata* (4.86 flowers/min.). Our findings get support from Kumar (1997); Mehta (2009) and Joshi and Joshi (2010).

(b) Afternoon hours

The mean foraging rate was found highest for *A. cerana* (10.14 flowers/min.) followed by *A. mellifera* (9.17 flowers/min.) and *A. dorsata* (6.72 flowers/min.). The records of mean foraging rate and speed were almost similar as reported by Mehta (2009) and Kumar et al. (2018).

As also shown in Fig. 4.14 that in morning hours foraging rate of *A. cerana* was maximum at Palampur (10.08 flowers/min.) followed by Bharwar (7.75 flowers/min.) and lowest was at Jachh (6.33 flowers/min.). But during afternoon hours (Fig. 4.15) foraging rate of *A. cerana* was high at Jachh (10.92 flowers/min.) followed by Bharwar (10.33 flowers/min.) and the lowest was at Palampur (9.17 flowers/min.).

4.3.3 Foraging speed

(a) Morning hours

Perusal of data in table 4.12 and Fig. 4.16, the mean foraging speed was found significantly higher in case of *A. mellifera* (6.83 sec.) followed *A. dorsata* (5.81 seconds) and *A. cerana* (4.89 sec.) in the morning hours. Our results get support by Kumar et al. (1996) who have reported the time spent by *A. mellifera*, *A. dorsata* and *A. cerana indica* was shown 5.8, 5.2 and 4.0 seconds respectively. Kumar and Gupta (1993) and Joshi and Joshi (2010) also confirm our results.

(b) Afternoon hours

As it is clear in Fig. 4.17 that the average foraging speed was found to be maximum in case of *A. cerana* (9.56 sec.) and *A. mellifera* (9.56 sec.) while both were at par with each other followed by *A. dorsata* (8.53 sec.). These findings for foraging speed during the afternoon hours, corroborated with the findings of Vishweshwaraiah et al. (2002) and Mehta (2009).

Table 4.11 Mean number of flowers visited by honeybee species, *Apis* spp. at different locations in Kangra district of Himachal Pradesh on guava, *Psidium guajava*

Location / Honeybee	Number of flowers visited by honeybee/ minute							
	Morning				Afternoon			
	Jachh	Palampur	Bharwar	Mean	Jachh	Palampur	Bharwar	Mean
Apis mellifera	5.58 (2.55)	6.92 (2.78)	7.67 (2.94)	6.72 (2.76)	10.50 (3.37)	8.17 (3.00)	8.83 (3.13)	9.17 (3.17)
Apis cerana	6.33 (2.67)	10.08 (3.31)	7.75 (2.91)	8.06 (2.97)	10.92 (3.44)	9.17 (3.18)	10.33 (3.35)	10.14 (3.33)
Apis dorsata	3.75 (2.16)	5.92 (2.62)	4.92 (2.41)	4.86 (2.41)	6.33 (2.69)	6.50 (2.72)	7.33 (2.87)	6.72 (2.76)
Mean	5.22 (2.46)	7.64 (2.90)	6.78 (2.75)		9.25 (3.17)	7.94 (2.97)	8.83 (3.12)	

Each value represents the mean value of 3 replicates.

Figures in parentheses are the means of $\sqrt{n+1}$ transformation.

CD (p=0.05) for:

Morning	C.D.(p=0.05)
Insect pollinator	NS
Location	0.39
Insect pollinator × Location	NS
C.V.	13.91

Afternoon	C.D.(p=0.05)
Insect pollinator	NS
Location	0.30
Insect pollinator × Location	NS
C.V.	9.52

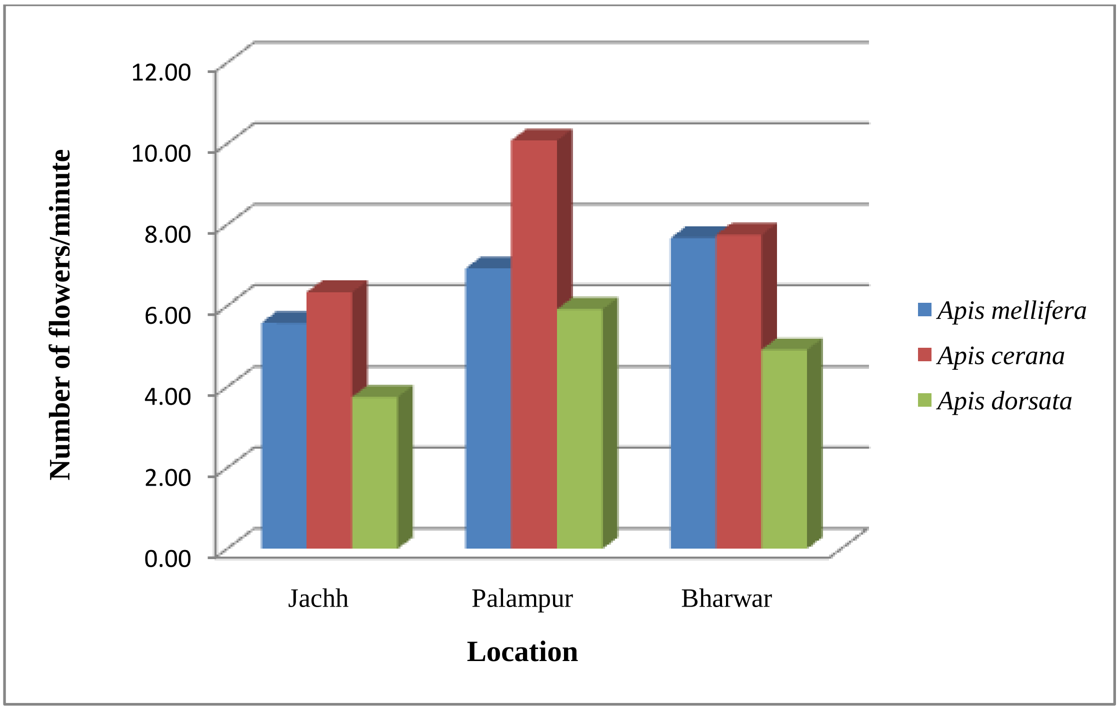


Fig. 4.14 Foraging rate of honeybees on *Psidium guajava* in morning hours

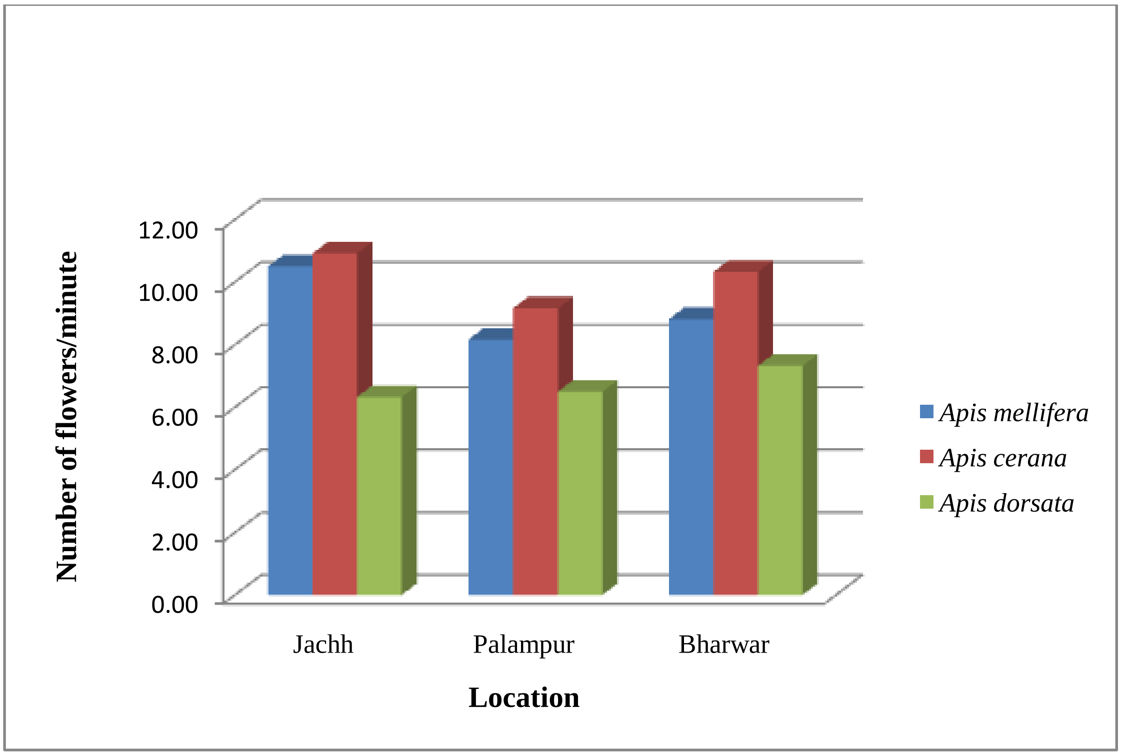


Fig. 4.15 Foraging rate of honeybees on *Psidium guajava* in afternoon hours

Table 4.12 Time spent (seconds) by honeybee species, *Apis* spp. at different locations in Kangra district of Himachal Pradesh on guava, *Psidium guajava*								
Location / **Honeybee**	**Time spent by honeybee/flower (seconds)**							
	Morning				Afternoon			
	Jachh	Palampur	Bharwar	Mean	Jachh	Palampur	Bharwar	Mean
Apis mellifera	6.58 (2.75)	6.08 (2.63)	7.83 (2.90)	6.83 (2.76)	10.00 (3.37)	8.50 (3.00)	10.17 (3.13)	9.56 (3.17)
Apis cerana	5.08 (2.46)	3.92 (2.21)	5.67 (2.57)	4.89 (2.41)	10.92 (3.44)	8.92 (3.18)	8.83 (3.35)	9.56 (3.33)
Apis dorsata	5.58 (2.52)	5.75 (2.56)	6.08 (2.66)	5.81 (2.58)	8.08 (2.69)	8.67 (2.72)	8.83 (2.87)	8.53 (2.76)
Mean	5.75 (2.57)	6.64 (2.47)	6.53 (2.73)		9.67 (3.17)	8.69 (2.97)	9.28 (3.12)	

Each value represents the mean value of 3 replicates.

Figures in parentheses are the means of $\sqrt{n+1}$ transformation.

CD (p=0.05) for:

Morning	C.D.(p=0.05)
Insect pollinator	NS
Location	NS
Insect pollinator × Location	NS
C.V.	17.53

Afternoon	C.D.(p=0.05)
Insect pollinator	NS
Location	0.30
Insect pollinator × Location	NS
C.V.	9.52

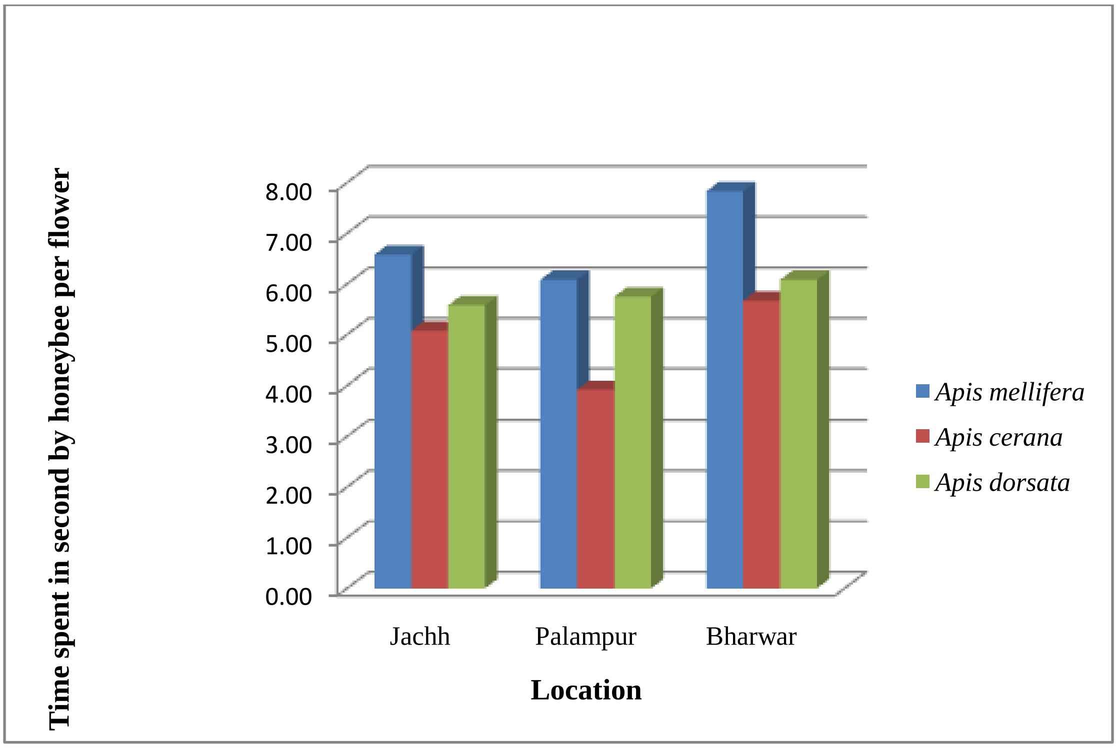


Fig. 4.16 Foraging speed of honeybees on *Psidium guajava* in morning hours

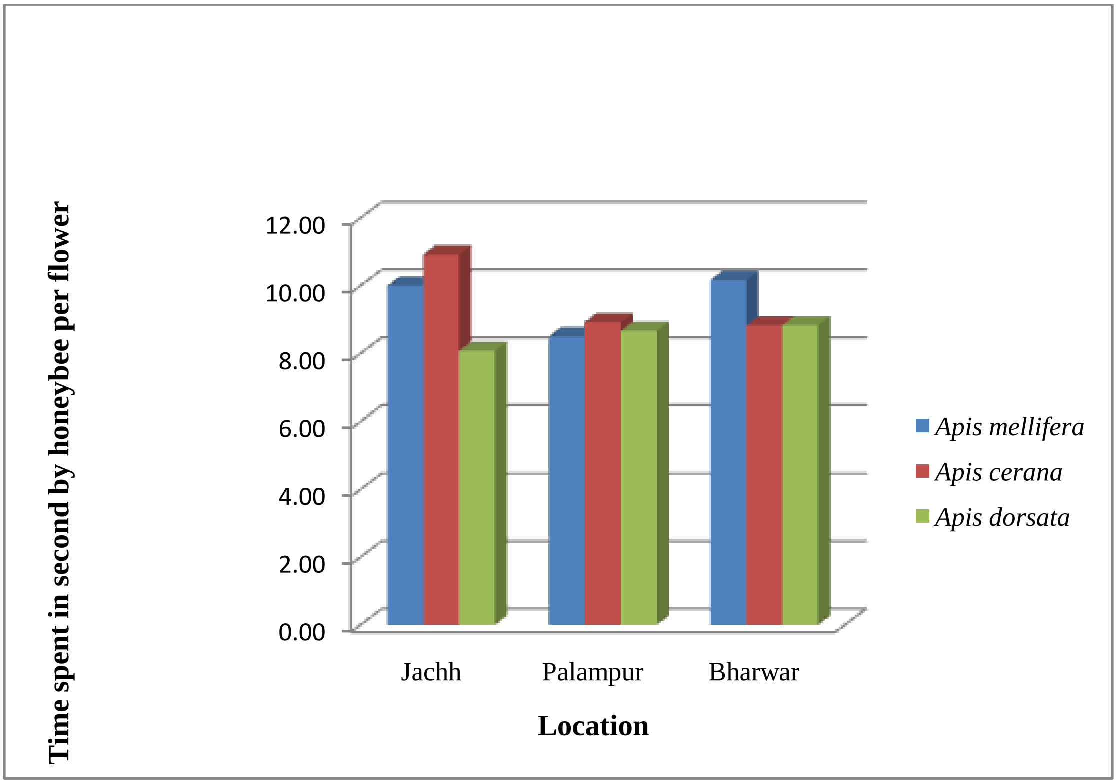


Fig. 4.17 Foraging speed of honeybees on *Psidium guajava* in afternoon hours

4.3.4 Foraging mode

Foraging mode of honeybee pollinators was recorded as the highest for *Apis dorsata* (2.16) followed by *A. mellifera* (1.50) and *A. cerana* (1.31). The average foraging mode of honeybees was found higher at Bharwar (2.23) followed by Jachh (2.03) and Palampur as 1.39 (as per Table 4.13). As it is apparent from the Fig. 4.18 that the percentage of top foragers was higher for *A. mellifera* than in *A. cerana*. Similar results with higher percentage of *A. mellifera* as top foragers than *A. cerana* were also in close conformity with Khamhari (2013).

Table 4.13 Foraging mode of honeybee species on *Psidium guajava* L. at different locations in Kangra district

Honeybee species	Type of Forager	Location: Ratio of foragers						
		Jachh		Palampur		Bharwar		Mean
Apis mellifera	Top foragers	11.00	1.22	9.00		16.00	4.00	1.50
	Side foragers	9.00		11.00	0.82	4.00		
Apis cerana	Top foragers	13.00	1.86\	12.00		9.00	0.82	1.31
	Side foragers	7.00		8.00	1.50	11.00		
Apis dorsata	Top foragers	15.00	3.00	13.00	1.86	13.00	1.86	2.16
	Side foragers	5.00		7.00		7.00		
Mean			2.03		1.39		2.33	

20 individuals for each honeybee species were observed.

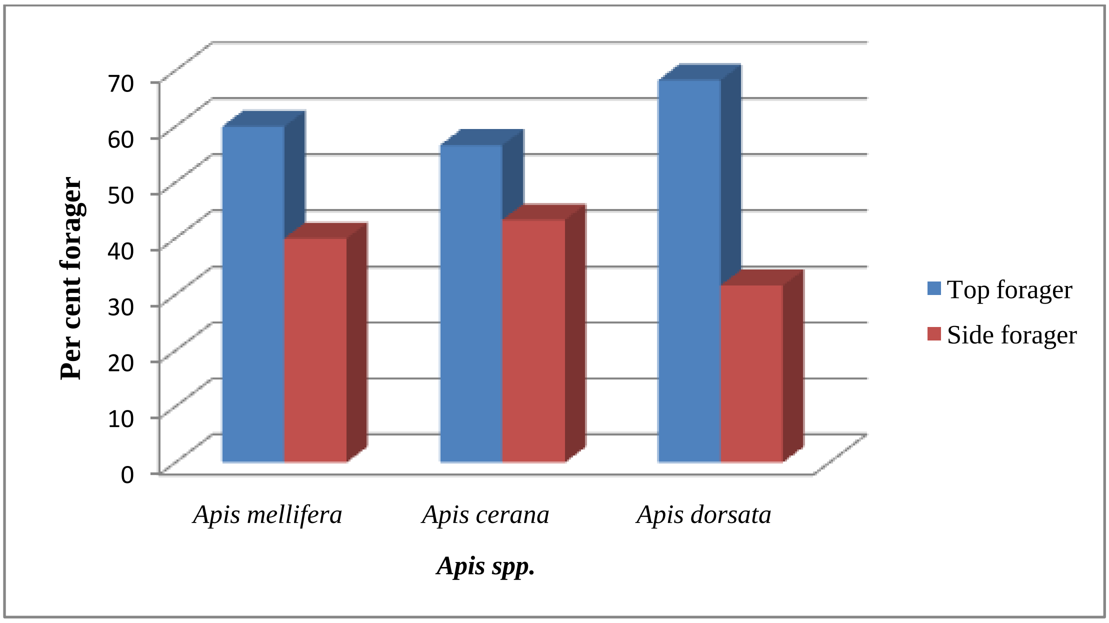


Fig. 4.18 Types of foragers in *Psidium guajava*

4.3.5 Number of pollen grains adhering to the body of honeybee species

(a) Body of honeybees

The data on loose pollen grains indicated that among *Apis* pollinators maximum loose pollen grains (4,54,000) were adhered to the body of *Apis dorsata* followed by *A. mellifera* (4,14,000) and *A. cerana* (3,52,000) (as per Table 4.14). Our findings had no significant differences among species in the count of loose pollen grains sticking to their body. In a study conducted at Hisar by Mehta (2009) supports our results with a similar trend. Based on above results and support it can thus be concluded that the pollen carrying capacity of honeybees depends on their body weight.

(b) Hind legs of honeybees

The data on counts of pollen grains on hind legs (present in the form of pellets) showed that among *Apis* pollinators maximum number of pollen grains (4,18,000) were seen in *Apis dorsata* followed by *A. mellifera* (3,60,000) and *A. cerana* (1,94,000). Significant difference was observed in the number of pollen grains sticking to the hindlegs of honeybees of different species (as per Table 4.14).

4.3.6 Pollination efficiency index (P.E.I.) of honeybees on *Psidium guajava*

Perusal of data as per table 4.14 represents the pollination efficiency of three honeybee species foraging on guava flowers. According to the above three attributes *i.e.* abundance, foraging rate and number of loose pollen grains sticking to the body of each honeybee pollinator, ranking of *Apis* pollinators was done. The pollination efficiency index of *A. cerana* (6.54) was consequently found highest compared to *A. dorsata* (6.52) and *A. mellifera* (6.33). There was no confirmatory support to our findings of P.E.I. in guava crop. However, Hedstrom (1988), Kumar et al. (1996) and Vishweshwaraiah et al. (2002) have reported *A. mellifera* as the most efficient pollinator of guava. This may again be due to the agro-climatic conditions as well as the abundance of *A. cerana* feral colonies in our experimental locations and vice-versa.

Table 4.14 Pollination efficiency of different bee species on guava, *Psidium guajava*							
Honeybee species	*Abundance	**Foraging rate	Loose pollen grains sticking on the body of bees	Loose pollen grains sticking to pollen pellets on the hind legs	Pollination efficiency (abundance × foraging rate × loose pollen grains)	Log_{10} value of pollination efficiency or P.E.I.	P.E.I. Rank
Apis mellifera	0.65	7.94	4,14,000.00	3,60,000.00	21,36,654.00	6.33	3rd
Apis cerana	1.08	9.10	3,52,000.00	1,94,000.00	34,59,456.00	6.54	1st
Apis dorsata	1.25	5.79	4,54,000.00	4,18,000.00	32,85,825.00	6.52	2nd

Each value represents the mean value of 5 replicates for count of pollen grains on body and hind legs.

*Abundance of honeybees is the mean value of relative abundance in early and peak bloom.

**Foraging rate is the mean value of number of flowers visited by honeybee/minute in morning and afternoon hours.

5. SUMMARY AND CONCLUSIONS

The present investigations entitled "Pollination potential of *Apis* species on guava and litchi" were carried out at Bee Research Station, Nagrota Bagwan of Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur during the year 2019-20. On litchi, studies were conducted at Palampur, Nagrota, Sulah and Saliana and in guava, at Jachh, Palampur and Bharwar of district Kangra of Himachal Pradesh. The results on diversity of insect visitors and their relative abundance, foraging intensity, foraging rate, foraging speed, foraging mode and pollinator efficiency index of honeybees on both the fruit crops have been summarized as under:

- Diversity of insect pollinators in litchi and guava ecosystems at six locations in Kangra district was 51 insects, and majority of insects were of order Hymenoptera and Diptera.
- Honeybees were found to be the most abundant pollinators during early bloom in litchi (42.63 %) and during early bloom (50.65 %) and peak bloom (59.90 %) in guava, respectively.
- Honeybee population in litchi during morning hours and afternoon hours was 39.64 % and 44.84 % while it was 51.21 % and 60.45 % in guava ecosystems. The combined assessment of insect visitors revealed that the insect activity completely ceased at 8 PM.
- In litchi, *A. mellifera* (17.7 %) and *A. cerana* (20.08 %) were dominant among honeybees, however, in guava; *A. dorsata* (26.80 %) and *A. cerana* (22.80 %) were predominant during early bloom and peak bloom, respectively. Foraging intensity at Sulah, Saliana, Nagrota and Palampur was 0.45, 0.19, 0.36 and 0.10 at early bloom and 0.65, 0.45, 0.67 and 0.61 insects/m^2/min. at peak bloom of litchi, respectively. The foraging intensity at Jachh, Bharwar and Palampur was 0.33, 0.47 and 0.31 at early bloom whereas 0.96, 0.88 and 0.73insects/m^2/min. at peak bloom of guava, respectively.

- Foraging rate at Sulah, Saliana, Nagrota and Palampur was 9.47, 7.94, 9.11and 8.19 in morning hours and 9.28, 9.67, 10.08 and 8.69 flowers/min. in afternoon hours in litchi ecosystem, respectively. The foraging rate at Jachh, Bharwar and Palampur was 5.22, 6.78, and 7.64 in morning hours and 9.25, 8.83 and 7.94 flowers/min. in afternoon hours in the guava ecosystem, respectively. The mean foraging rate was highest for *A. cerana* (10.19 flowers/min.) during morning hours and *A. mellifera* (10.04 flowers/min.) in afternoon hours in litchi. Similarly, in guava, it was maximum for *A. cerana* during both morning and afternoon hours.
- Foraging speed at Sulah, Saliana, Nagrota and Palampur was 5.27, 6.06, 6.86 and 7.44 in morning hours and 6.34, 6.33, 6.73 and 8.52 seconds in afternoon hours in litchi ecosystem. The foraging speed at Jachh, Bharwar and Palampur was 5.75, 6.53 and 6.64 in morning hours and 9.67, 9.28 and 8.69 seconds in afternoon hours in guava ecosystem, respectively. The mean foraging speed was highest for *A. dorsata* (7.55 sec.) during morning hours and *A. cerana* (7.34 sec.) in afternoon hours in litchi. Similarly, in guava, it was maximum for *A. mellifera* (6.83 sec.) during morning hours and *A. cerana* and *A. mellifera* (9.56 sec.) in afternoon hours.
- Foraging mode at Saliana, Nagrota, Sulah and Palampur was 3.49, 2.17, 2.12 and 1.31 in litchi and at Bharwar, Jachh and Palampur was 2.23, 2.03 and 1.39 in guava ecosystems, respectively. The mean foraging mode was found higher for *A. mellifera* (2.33) and *A. dorsata* (2.16) in litchi and guava crop ecosystems, respectively.
- The pollination efficiency index (P.E.I.) of *A. mellifera* (6.27) was highest compared to *A. cerana* (6.24) and *A. dorsata* (5.99) in litchi ecosystem. The pollination efficiency index of *A. cerana* (6.54) was highest compared to *A. dorsata* (6.52) and *A. mellifera* (6.33) in guava ecosystem.

Based on the outcome of the present investigation, it can be concluded that the litchi and guava ecosystems had 51 insect pollinators, majority of which were dipteran and hymenopteran. The activity of insects was comparatively higher in morning hours while completely ceased at 8 PM, hence an environmental safe window of late afternoon insecticide application if necessary can be done. Wild honeybees, *A. dorsata*, feral colonies of *A. cerana* and syrphids were found to be the major pollinators along with the hived honeybees. P.E.I. of *A. mellifera* and *A. cerana* was highest compared to other pollinators in litchi and guava ecosystems, respectively. The information generated from this study would be helpful to farmers and developmental agencies for the importance and conservation of pollinators.

LITERATURE CITED

Abrol DP. 1993. Insect pollination and crop production in Jammu and Kashmir. *Current Science* 65: 265-69

Abrol DP. 2006. Diversity of pollinating insects visiting litchi flowers (*Litchi chinensis* Sonn.) and path analysis of environmental factors influencing foraging behavior of four honeybee species. *Journal of Apicultural Research* 45(4): 180-187

Abrol DP. 2009. Plant-pollinator interactions in the context of climate change - an endangered mutualism. *Journal of Palynology* 45:1-25

Adlakha RL, Dhaliwal HS and Srivastva S. 1979. Insect pollination of litchi, *Litchi chinensis* Sonn. in the valley areas of Indian Himalayas. In: Proceedings of the National Symposium on Pollination Ecology and Applied Palynology, Hisar, India. P. 2-3

Ahmad SB, Dar SA and Pandith BA. 2017. Comparative foraging behavior of honeybees, *Apis cerana* F. and *Apis mellifera* L. (Hymenoptera: Apidae) on apple bloom. *Journal of Entomology and Zoology Studies* 5(1): 474-482.

Akratanakul P. 1987. Honeybee diseases and enemies in Asia. A practical guide. FAO (Food and Agriculture Organization). Rome, Italy.

Amin D, Ahmad M, Shifa and Ibrahim S. 2018. Insect pollinator diversity in major traditional leafy vegetables kale (*Brassica oleracea* var. *acephala*) and knol-khol (*Brassica oleracea* var. *gongylodes*) of Kashmir Himalayas. *International Journal of Current Microbiology and Applied Sciences* 7(3): 3082-3089.

Anderson DL, Sedgeley M, Short JRT and Atwood AJ. 1982. Insect pollination of Mango in northern Australia. *Australian Journal of Agricultural Research* 33: 541-548.

Anita M, Sivaram V and Jayaramappa KV. 2012. Influence of bee attractants on pollination and yield parameters in guava (*Psidium guajava* L.). *The International Journal of Plant Reproductive Biology* 4(1): 13-16.

Anonymous. 2018. Horticulture Area Production Info System. Ministry of Agriculture and Farmers' Welfare http://aps.dac.gov.in (21st December, 2018).

Araujo VA, Antonini Y and Araujo APA. 2006. Diversity of bees and their floral resources at altitudinal areas in the Southern Espinhaco Range, Minas Gerais, Brazil. *Neotropical Entomology* 35(1): 30-40.

Bajiya MR and Abrol DP. 2017. Flower-visiting insect pollinators of mustard (*Brassica napus*) in Jammu Region. *Journal of Pharmacognosy and Phytochemistry* 6(5): 2380-2386

Bharti V, Ahlawat DS, Sharma SK, Singh NV, Jitender and Singh N. 2015. Diversity, abundance and pollination efficiency of insect pollinators of fennel (*Foeniculum vulgare* Miller) and effect of abiotic factors on insect pollinator activity. *Journal of Applied and Natural Science* 7 (2): 786 -793.

Bhatia R, Gupta D, Chandel JS and Sharma NK. 1995. Relative abundance of insect visitors on flowers of major subtropical fruits in Himachal Pradesh and their effect on fruit set. *Indian Journal of Agricultural Sciences* 65 (12): *907-912.*

Biesmeijer JC, Roberts SPM, Reemer M, Ohlemulle R, Edward M, Peeters T, Schaffers AP, Potts SG, Kleuker R, Thomas CD, Settele J and Kunin WE. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science* 313(5785): 351-354.

Bohart GE and Nye WP. 1960. Insect pollinators of Carrots in Utah. Bulletin of Utah Agriculture Experimental Station, Logan, Utah. 419:16-17

Bond WJ. 1994. Do mutualisms matter? Assessing the impact of pollinator's disperser disruption on plant extinction. *Philosophical Transactions of the Royal Society of London Series B* 344 (1307): 83-90

Boti JB, Campos LA de O, Junior P de M and Vieira MF. 2005. Influence of distance forest fragments in guava plant pollination. *Revista ceres* 52(304): 863-874.

Brittain C, Kremen C, Garber A and Klein AM. 2014. Pollination and plant resources change the nutritional quality of almonds for human health. *PLoS One* 9(2): e90082.

Buchmann SL and Nabhan GP. 1996. The Forgotten Pollinators. Island Press, USA.

Camillo E and Grafalo CA. 1989. Analysis of the niche of the two sympatric species of *Bombus* (Hymenoptera, Apidae) in South Eastern Brazil. *Journal of Tropical Ecology* 5: 81-92

Castro MS and Araujo VML. 1998. Visit of Bees (Hymenoptera; Apoidea) to guava flowers (*Psidium guajava* L.). In: XV Brazilian Congress of Fruticulture, Belem, Brazil. P 367

Chadha KL and Rajpoot NS. 1969. Studies on floral biology, fruit set and its retention and quality of some litchi varieties. *Indian Journal of Horticulture* 23: 124-29

Chaudhary OP and Singh J. 2007. Diversity, temporal abundance, foraging behavior of floral visitors and effect of different modes of pollination on coriander (*Coriandrum sativum* L.). *Journal of Spices and Aromatic Crops* 16(1): 26-32

Crane E and Walker P. 1984. Pollination Directory for World Crops. International Bee Research Association, London, UK.

Crane E. 1990. Bees and beekeeping: Science practice and world resources, Hinemann Newnes, Oxford, UK.

Dalio JS. 2018. Foraging frequency of *Apis* species on bloom of *Brassica napus* L. *The International Journal of Engineering and Science* 7(2): 28-33

Dar SA, Mir GM, Wani AR, Kandoo AA and Nissar M. 2018. Insect pollinators of peach *Prunus persica* in landscapes of temperate India. *International Journal of Chemical Studies* 6(3): 1281-1284.

Das CS and Choudhury R. 1958. Floral biology of *Litchi chinensis* Sonn. *South Indian Horticulture* 6: 17-22

Das R and Jha S. 2018. Record of insect pollinators and their abundance on Indian mustard (*Brassica juncea* L.) in New Alluvial Zone of West Bengal. *Journal of Pure and Applied Biosciences* 6(5): 848-853

Das R, Jha S and Halder A. 2019. Insect pollinators of litchi with special reference to foraging behavior of honeybees. *Journal of Pharmacognosy and Phytochemistry* 8(4): 396-401.

Dasarathy TB. 1951. The guava. *Madras Agricultural Journal* 38: 521-527

Dashad SS. 1989. Pollination studies on apple (*Malus domestica* Borkh.) with particular reference to the role of the honeybees. Ph D Thesis, Department of Entomology, Dr. Y.S. Parmar University of Horticulture and Forestry, Solan, India

Delaplane KS and Mayer DF. 2000. Crop Pollination by Bees. CABI Publishing, New York. Inc. p 352.

Devkota FP. 2000. Impacts of bee pollination on the yield of broccoli (*Brassica campestris* L var. *botrytis*) under Chitwan conditions. M Sc Thesis, Institute of Agricultural Sciences and Animal Sciences, Rampur, Chitwan, Nepal

Dhakal G. 2003. Efficiency of *Apis mellifera* L. and *Apis cerana* F. for pollinating mustard and buckwheat. M Sc Thesis, Institute of Agricultural Sciences, Rampur, Chitwan, Nepal

Dhaliwal HS, Srivastava S and Adlakha RL. 1977. Insect pollination of Lychee (*Litchi chinensis* Sonn.) in the valley areas of Indian Himalayas. In: Proceedings of the XXVI International Apiculture Conference. Acapulco Mexico. Bucharest. P. 386-38

Dubey D, Thapa RB, Tiwari S, Gautam B and Sapkota P. 2020. Diversity, relative abundance, and diurnal variation of insect visitors of litchi (*Litchi chinensis* Sonn.) at

Rampur, Chitwan, Nepal. *Entomology, Ornithology & Herpetology: Current Research* 9: 22.

Eilers EJ, Kremen C, Smith Greenleaf S, Garber AK and Klein AM. 2011. Contribution of pollinator-mediated crops to nutrients in the human food supply. *PLoS One* 6(6): e21363.

Free JB. 1970. Insect Pollination of Crops. Academic Press, London, U.K.

Free JB. 1993. Insect Pollination of Crops, Academic Press, London, U.K.

Freitas BM and Alves JE. 2008. Effect of number of floral visits by honeybee (*Apis mellifera*) in the pollination of guava (*Psidium guajava* L). *Revista Ciencia Agronomica* 39(1): 148-154

Frund J, Linsenmair KE and Bluthgen N. 2010. Pollinator's diversity and specialization in relation to flower diversity. *Oikos* 119(10): 1581-1590.

Gallai N, Salles JM, Settele J and Vaissiere BE. 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics* 68:810-821.

Garibaldi LA, Aizen MA, Klein AM, Cunningham SA and Harder LD. 2011. Global growth and stability of agricultural yield decrease with pollinator dependence. In: Proceedings of the National Academy of Sciences of the United States of America. P 5909–5914

Garratt MP, Breeze TD, Jenner N, Polce C, Biesmeijer JC and Potts SG. 2014. Avoiding a bad apple: Insect pollination enhances fruit quality and economic value. *Agriculture, Ecosystems & Environment* 184(100): 34-40.

Gathmann A, Greiler HJ and Tscharntke T. 1994. Trap-nesting bees and wasp colonizing set-aside fields: succession and body size, management by cutting and sowing. *Oecologia* 98: 8-14.

Gilbert FS. 1980. Flower visiting by hover flies. *Annual Review of Ecology, Evolution, and Systematics* 6: 139-170

Goulson D. 1999. Foraging strategies of insects for gathering nectar and pollen, and implications for plant ecology and evolution. *Perspectives in Plant Ecology, Evolution and Systematics* 2: 185-209

Gupta JK and Gupta PR. 1997. Diversification of pollinators. In: Fruit Crops Pollination. Kalyani Publishers, Ludhiana, India

Gupta MR and Nijjar GS. 1978. Crop regulation in guava. *Indian Journal of Horticulture.* 35: 23-27

Hayes WB. 1974. Fruit growing in India. Kitabistan, Allahabad, India.

Hedstrom. 1988. Pollen carriers and fruit development of *Psidium guajava* L. (Myrtaceae) in the Neotropical region. *Revista de Biologia Tropical* 36(2): 551-553

Hussain A. 2011. Role of honeybees in the pollination of guava (*Psidium guajava* L.). M Sc Thesis, Department of Apiculture, University of Agricultural Sciences GKVK, Bangalore, India

Inouye DW. 1980. The effect of proboscis and corolla tube lengths on patterns and rates of flower visitation by bumble bees. *Oecologia* 45: 197-210

Inouye DW. 2001. Role of pollinators. *Enclycopedia of Biodiversity* 4: 723-730

Jarlan A, Oliveira de D and Gingras J. 1997. Pollination of sweet pepper (*Capsicum annuum* L.) in greenhouse by the Syrphid fly *Eristalis tenax* (L.). *Acta Horticulturae* 437: 335-340.

Joshi NC and Joshi PC. 2010. Foraging behavior of *Apis* species on apple flowers in subtropical environment. *New York Science Journal* 3(3): 71-76

Kaur H and Sharma SK. 2020. Foraging fidelity of honeybees and abundance of insect visitors on some Horticultural crops. *International Journal of Chemical Studies* 8(3): 1974-1978

Khamhari D. 2013. Role of honeybee pollination in niger with special reference to *Apis mellifera.* M Sc Thesis, Department of Agricultural Entomology, Birsa Agricultural University, Ranchi, Jharkhand, India

Kitroo A and Abrol DP. 1996. Studies on pollen carrying capacity and pollination efficiency of honeybees visiting litchi flowers. *Indian Bee Journal* 68(1): 55-57

Klatt BK, Holzschuh A, Westphal C, Clough Y, Smit I, Pawelzik E and Tscharntke T. 2014. Bee pollination improves crop quality, shelf life and commercial value. In**:** Proceedings of the Royal Society B: Biological Sciences, United Kingdom. P 281(1775): 20132440

Klein AM, Vaissiere BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C and Tscharntke T. 2007. Importance of pollinators in changing landscapes for world crops. In: Proceedings of the Royal Society Series B. Biological Sciences, United Kingdom. P 274(1608): 303-313

Kozin RB. 1972. Pollination of entomophilous crops by bees. *Amrind Publishing Company*. *Private Limited*, *New York.*

Kuberappa GC, Eswarappa G, Vishweshwaraiah CH and Sajjad SM. 2002. Activity and abundance of insects visiting guava (*Psidium guajava* L.) flowers. *Pest Management and Economic Zoology* 11(1): 59-63.

Kumar D. 1995. Bioecology of *Apis* and its mite pests in relation to almond and peach pollination. Ph D Thesis, Himachal Pradesh University, Shimla, India

Kumar H. and Gupta J.K. 1993. Pollination efficiency *of Apis cerana indica* F. and *Apis mellifera* L. on some important crops of Himachal Pradesh. In: Pollination in Tropics (lUSSI - Indian Chapter), Bangalore, India. P. 203 - 204

Kumar L. 1997. Foraging ecology and behavior of *Apis cerana* F. and *Apis mellifera* L. in pollinating apple and cherry flowers. Ph D Thesis. Himachal Pradesh University, Shimla, India

Kumar N, Rawat DS, Bharti and Tiwari P. 2018. Abundance and visitation rate of *Apis* pollinators on flowers of some multipurpose tree species grown in Muzaffarpur, Bihar, India. *Indian Journal of Scientific Research* 8(2): 29-34.

Kumar R and Kumar V. 2014. Impact of pollination by European honeybee, *Apis mellifera* L. on the yield and quality of litchi (*Litchi chinensis* Sonn.) fruits in India. *Pest Management in Horticultural Ecosystems* 20(2): 127-132

Kumar R, Chaudhary OP and Lenin JK. 2000. Studies on pollination of litchi (*Nephelium litchi* Camb.) in Dehradun, India. *Indian Bee Journal* 58(1): 9-12.

Kumar R, Lenin JK and Chandran K. 1996. Honeybee and pollination of *Psidium guajava* L. *Indian Bee Journal* 56(4): 206-207.

Kumar R. 2014. Planned honeybee pollination in Litchi (*Litchi chinensis* Sonn.) - a new production strategy for enhancing fruit yield and quality in India. *Acta Horticulturae* 1029: 281-286

Kumar S.1990. Studies on insect pollination in ber (*Ziziphus mauritiana* Lamk.). M Sc Thesis, Department of Entomology, Haryana Agricultural University, Hisar, Haryana, India

Lakshmi K and Rao GM.1998. Plants for bees-guava. *Bee world* 79(3): 135-137

Levin MD and Waller GD. 1989. Evaluating the role of honeybees in food production. *Apiacta* 3: 65-69

Maeta Y and Kitamura T. 1981. Pollination efficiency of *Osmia cornifrons* in relation to the number of bees required for economic fruit production. *Honeybee Science* 2(2): 65-72

Mani MS and Sarvanan JM. 1999. Pollination Ecology and Evolution in Compositae (Asteraceae). Oxford &IBH Publication Company Private Limited, Inc.p 165.

Mann GS and Dhooria MS. 1994. Activity and abundance of insects visiting of guava flowers in Punjab. *Journal of Insect Science* 7(2): 218-219

Marini L, Tamburini G, Petrucco-Toffolo E, Lindström SAM, Mosca G, Zanetti F and Bommarco R. 2015. Crop management modifies the benefits of insect pollination in oilseed rape. *Agriculture, Ecosystems & Environment* 207: 61-66.

Mattu VK and Bhagat T. 2015. Pollinator diversity and relative abundance of insect visitors on apple crop in Kullu hills of western Himalaya India. *International Journal of Scientific Research* 4: (6) 2277-8179

Mattu VK. 1982. Morphometric and behavioral studies on Indian honeybee (*Apis cerana indica*). Ph D Thesis, Department of Bio-Sciences, Himachal Pradesh University, Shimla, India

Mayer DF and Lunden JD. 1988. Honeybee foraging in crab apple orchards. *Journal of Entomological Society of British Columbia* 88: 15-17

McGregor SE. 1976. Insect pollination of cultivated crop plants, ARS, USDA, Agriculture Handbook No. 496, Washington, USA.

Mehta N. 2009. Diversity, visitation frequency and pollination ecology of insect pollinators of *Psidium guajava* L. (Guava). Ph D Thesis, Department of Zoology and Aquaculture. Chaudhary Charan Singh Haryana Agricultural University, Hisar, India

Menzel CM 2001. The physiology of growth and cropping in lychee. South African Litchi Growers' Association Yearbook. 12: 9-14

Menzel CM and Waite GK. 2005. Litchi and longan: botany, production and uses. CABI Publishing, New York. Inc.p 250.

Mishra M and Kumar N. 2018. Foraging behavior of honeybees on litchi bloom. *Environment & Ecology* 36(1):120-126

Mishra RC and Sharma SK. 1998. Technology for management of *Apis mellifera* in India. In: Perspectives in Indian Agriculture (RC Mishra et al., eds.). Kalyani Publishers, New Delhi, India. P 131-148

Mitra SK and Bose TK. 1990. Guava. In: Fruits: Tropical and Subtropical (SK Mitra;et al., eds.). Nayaprakash, Kolkata, India. P 610-652

Mogren CL, Rand TA, Fausti SW, Lundgren JG. 2016. The effects of crop intensification on the diversity of native pollinator communities. *Environmental Entomology* 45(4): 865-872.

Morandin LA and Winston ML. 2006. Pollinators provide economic incentive to preserve natural land in agro ecosystems. *Agriculture, Ecosystems and Environment* 116: 289-292

Mushtaq T, Ahmad SB, Aziz MA, Mushtaq T. 2017. Pollinator diversity and relative abundance of insect visitors on apple (*Malus domestica* Borkh) in Kashmir valley. *Indian Journal of Ecology* 44(4): 213-219.

Nayak RK, Rana K, Sharma HK, Singh P, Thakur S and Yankit P. 2019. Foraging behavior of bumble bees (*Bombus haemorrhoidalis* Smith) and honeybees (*Apis mellifera* L.) on Kiwifruit (*Actinidia deliciosa* Chev.). *International Journal of Current Microbiology and Applied Sciences* 8(5): 2043-2051.

Neupane KR. 2001. Foraging preferences of honeybee species to selected cultural crops. M Sc Thesis. Institute of Agricultural Sciences and Animal Sciences, Rampur, Chitwan, Nepal

Omoloye AA and Akinsola PA. 2006. Foraging sources and effects of selected plant characteristics and weather variables on the visitation intensity of honeybee, *Apis mellifera adonsonii* (Hymenoptera; Apidae) in the Southwest Nigeria. *Journal of Apicultural Science* 50(1): 39-48

Pandey RS and Yadava RPS. 1970. Pollination of litchi (*Litchi chinensis*) by insects with special reference to honeybees. *Journal of Apicultural Research* 9: 103-105

Partap U and Partap T. 1997. Managed crop pollination: The missing dimension of mountain agricultural productivity. Mountain Farming System's Discussion Paper Series No 97/1. ICIMOD, Kathmandu, Nepal

Pashte VV and Kulkarni SR. 2015. Role of pollinators in qualitative fruit crop production: A Review. *Trends in Biosciences* 8(15): 3743-3749

Phadke KG and Naim M. 1974. Observations of honeybee visitation to the Litchi. *Indian Bee Journal* 36: 9-12

Potts S. 2015. Key findings of the STEP project. Status and Trends of European Pollinators. Pensoft Publishers, Sofia. Inc.p 72

Potts SG, Dafni A and Neeman G. 2001. Pollination of a core flowering shrub species in Mediterranean phrygana: variations in pollinator diversity, abundance and effectiveness in response to fire. *Oikos* 92: 71– 80.

Raj D, Rana VK and Devi N. 1993. Comparative studies on the pollen loads of *Apis mellifera* L. and *Apis cerana indica* F. on rapeseed. *Journal of Entomological Research* 17(1):43-48.

Raj H, Mattu VK and Thakur ML. 2012. Pollinator diversity and relative abundance of insect visitors on apple crop in Shimla hills of Western Himalaya, India. *International Journal of Science and Nature* 3(3): 507-513.

Rajagopal D and Eswarappa G. 2005. Pollination potentiality of honeybees in increasing productivity of guava in Karnataka. *Advances in Pollen Spore Research* 22: 131-141

Rana RS. 1989. Aggressive and hoarding behavior of *Apis mellifera* L. and *Apis cerana* F. and their role in pollination of plum and apple bloom. Ph D Thesis, Department of Bio-Sciences, Himachal Pradesh University, Shimla, India

Rani D, Triveni B, Nandini and Reddy NG. 2017. Study of evaluation of foraging behavior of major insect pollinators on summer squash (*Cucurbita pepo* L.). *Journal of Entomology and Zoology Studies* 5(5): 28-30.

Rao GM and Lazar M. 1980. Studies on bee behavior and pollination in onion (*Allium cepa* L.). Apiculture Tropical Climates. In: Proceedings of the 2nd International Conference. New Delhi, India. P.580-589

Robinson WS. 1979. Effect of apple cultivar on foraging behavior and pollen transfer by honeybees. *Journal* of the *American Society* for *Horticultural Science* 104: 596-598

Rosemeire AG, Rachel PM and Maria AC. 2009. Bee diversity in a commercial guava orchard in Salinas, Minas Gerais State, Brazil. *Bragantia* 68(1): 23-27.

Roubik DW. 1995. Pollination of cultivated plants in the tropics. FAO Agricultural Services Bulletin 118, Rome.

Sarkar TK and Bandyopadhyay A. 1989. Flowering behavior of some important litchi (*Litchi chinensis* Sonn.) varieties of the Gangetic Plains of West Bengal. *Environment and Ecology* 7: 189-92

Sharma HK, Bakshi N, Thakur RK and Devi M. 2016. Diversity and density of insect pollinators on sweet cherry (*Prunus avium* L.) in temperate region of Kullu valley of Himachal Pradesh. *Journal of Entomological Research* 40(2): 123-128.

Sharma HK, Gupta JK, Suman V and Belavadi VV. 2015. Studies on flowering phenology, pollinator diversity, supplemented pollination and their impact on fruit set in apple under changing climatic scenario in Kullu valley of Himachal Pradesh. *International Journal of Farm Sciences* 5(4): 156-164.

Sharma K, Singh B, Meena NK and Meena RS. 2018. Foraging behavior of major *Apis* species on coriander. *International Journal of Current Microbiology and Applied Science* 7(1): 2928-2932.

Sharma N. 1989. Melissopalynology and survey of honey plants in Himachal Pradesh. Ph D Thesis, Department of Bio-Sciences, Himachal Pradesh University, Shimla, India

Sharma RM and Mitra B. 2012. A preliminary study on insect pollinators of temperate fruit crops in Himachal Pradesh. *Zoological Survey of India* 111(3): 103-110

Sihag RC. 1997. Determining the efficiency of pollinators: In: Pollination Biology: Basic and Applied Principles (RC Sihag, eds.). Rajendra Scientific Publishers, Hisar, India. P171-186

Singh R and Garg R. 1994. Relative abundance of insect visitors and pollination requirements of citrus. *Pest Management and Economic Zoology* 2(2): 143-146

Singh R and Garg R. 2003. Role of honeybees in sustainable food production. *Indian Bee Journal* 65(1-2): 61-67

Singh SP. 1988. Insect pollination studies on almond. Ph D Thesis, Department of Entomology, Dr. Y.S. Parmar University of Horticulture and Forestry, Solan, India

Singh UR and Kumar R. 1993. Crop regulation in guava. In: Advances in Horticulture (Chadha KL and Pareek O ; et al., eds.). Malhotra Publishing House, New Delhi, India. P 50-52

Srawan BS and Sohi BS. 1985. Phytosociological studies on *Apis mellifera* L. and *Apis cerana* indica Fab. in Punjab, India. *Indian Bee Journal* 47: 15-18

Srivastava K, Sharma D, Pandey SD, Anal AKD and Nath V. 2017. Dynamics of climate and pollinator species influencing litchi (*Litchi chinensis*) in India. *Indian Journal of Agricultural Sciences* 87(2): 266-269.

Tanda AS. 1983. Assessing the role of honeybees in field of Asiatic cotton (*Gossypium arboreum* L.). *American Bee Journal* 123(8): 593-594

Thakur B and Mattu VK. 2014. Diversity and distribution of pollinators of temperate fruit crops of Shimla hills in Himachal Pradesh. *Asian Journal of Advanced Basic Sciences* 3(1): 151-163

Thapa RB. 2002. Insect pollinators of some crop plants in Chitwan. NAHSON Bulletin 12/13: 19-21.

Thapa RB. 2006. Honeybees and other insect pollinators of cultivated plants: A review. *Journal of the Institute of Agriculture and Animal Science* 27: 1-23

Uppal DK, Sharma SK and Kumar K. 1997. Pollination mechanism in fruit crops. In: Fruit crops pollination (LR Verma and KK Jindal et al., eds.). Kalyani Publishers, Ludhiana, India. P 3-7

Usha, Srivastava P and Khan MS. 2009. Biodiversity of insect pollinators on litchi at Pantnagar. *Journal of Eco-friendly Agriculture* 4 (2): 196-197.

Verma LR and Chauhan P. 1985. Distribution, abundance and diversity of insect pollinators in apple orchards of Shimla hills. *Indian Journal of Ecology* 12: 286-92

Verma LR and Dulta PC. 1986. Foraging behavior of *Apis cerana indica* and *Apis mellifera* in pollinating apple flowers. *Journal of Apicultural Research* 25: 197-201

Verma LR and Rana RS. 1994. Further studies on the behavior of *Apis cerana* and *Apis mellifera* foraging on apple flowers. *Journal of Apicultural Research* 33(3): 175-178

Verma LR. 1990. Beekeeping in integrated mountain development: *Economic and Scientific Perspectives.* Oxford and IBH Publishing Company, New Delhi.

Verma LR. 1997. Potentials of bees and beekeeping for increasing fruit production through pollination. In: Proceedings of 'Fruit Crop Pollination." (LR Verma and KK Jindal, eds), Kalyani Publishers, Ludhiana. P.10-28

Vishweshwaraiah CH, Eswarappa G, Kuberappa GC, Sreenatha TN and Sreeramulu KR. 2002. Foraging activity and pollinating efficiency of different species of honeybees on quantitative and qualitative parameters of guava (*Psidium guajava* L.). *Pest Management and Economic Zoology* 10(2): 179-182.

Vithanage HIMV and DA Ironside. 1986. The insect pollinators of macadamia and their relative importance. *Journal of the Australian Institute of Agricultural Science* 52: 155-160

Vithanage HIMV. 1986. The role of insects in avocado pollination. In: Pollination '86, Proceedings of a Symposium (EG Williams;et al., eds.) Plant Cell Biology Research Center, School of Botany, University of Melbourne. Melbourne. Australia. P 42-47

Watanabe ME. 1994. Pollination worries rise as honeybees decline. *Science* 265(5176): 1170-1171

Widhiono L, Sudiana E and Sucianto ET. 2016. Insect pollinator diversity along a habitat quality gradient on Mount Slamet, Central Java, Indonesia. *Journal of Biological Diversity* 17(2): 746-752.

APPENDIX-I

Average monthly meteorological data of Nagrota Bagwan (April, 2019 to June, 2020)						
Month	Temperature (^oC)				Relative humidity (%)	Rainfall (mm)
	(Min.)	(Max.)	Dry	Wet		
April, 2019	17.40 ± 2.14	29.80 ± 2.83	26.33 ± 3.85	19.27 ± 2.13	53.00 ± 16.21	40.40
May, 2019	19.81 ± 1.82	32.52 ± 2.24	29.48 ± 4.00	19.29 ± 1.40	38.00 ± 7.78	36.50
June, 2019	22.53 ± 1.23	35.97 ± 1.76	32.10 ± 3.43	22.50 ± 1.26	45.53 ± 17.08	31.20
July, 2019	22.52 ± 1.41	30.77 ± 3.02	26.32 ± 2.70	23.97 ± 1.52	82.60 ± 12.30	361.20
August, 2019	23.02 ± 1.59	29.58 ± 1.77	26.35 ± 1.79	24.48 ± 1.19	85.52 ± 8.75	566.10
September, 2019	21.80 ± 1.66	28.77 ± 1.86	25.83 ± 2.49	23.53 ± 2.12	81.27 ± 7.95	361.40
October, 2019	16.00 ± 1.39	25.58 ± 1.19	22.61 ± 1.68	19.26 ± 1.24	73.35 ± 9.41	14.20
November, 2019	12.40 ± 1.75	21.45 ± 3.00	20.07 ± 3.91	72.4±15.90	16.77 ± 3.95	25.60
December, 2019	6.65 ± 1.33	15.61 ± 2.64	14.61 ± 3.10	10.68 ± 1.49	63.32 ± 16.46	80.00
January, 2020	4.94 ± 1.37	15.00 ± 1.67	13.10 ± 1.78	10.03 ± 1.51	68.90 ± 14.18	101.60
February, 2020	10.21 ± 1.73	19.69 ± 2.79	16.93 ± 2.78	12.38 ± 2.06	59.48 ± 12.64	9.80
March, 2020	10.71 ± 1.11	20.08 ± 2.48	19.31 ± 3.57	14.81 ± 2.55	63.29 ± 17.84	175.40
April, 2020	11.90 ± 1.37	23.37 ± 2.18	21.47 ± 1.80	16.00 ± 0.73	57.47 ± 11.88	32.00
May, 2020	14.35 ± 1.31	27.84 ± 3.18	26.61 ± 2.78	22.94 ± 3.54	73.00 ± 11.36	62.00
June , 2020	18.60 ± 4.27	31.90 ± 1.35	29.57 ± 1.31	25.30 ± 1.44	71.37 ± 11.39	62.00

APPENDIX-II

Average monthly meteorological data of Palampur (April, 2019 to June, 2020)							
Month	Temperature (^{0} C)		Relative humidity (%)		*BSS (hrs.)	Rainfall (mm)	**RD
	(Min.)	(Max.)	Morning	Afternoon			
April, 2019	13.91	26.60	58.00	44.00	8.10	57.40	6
May, 2019	16.63	29.30	50.00	38.00	8.50	42.40	8
June, 2019	20.00	32.20	49.00	42.00	8.50	29.20	8
July, 2019	19.85	27.71	86.00	79.00	3.90	421.90	24
August, 2019	19.47	26.80	92.00	85.00	3.50	628.80	23
September, 2019	17.74	26.65	92.00	83.00	4.60	286.9	15
October, 2019	11.90	24.12	78.00	67.00	7.20	39.30	9
November, 2019	9.00	20.34	77.00	66.00	4.30	68.20	8
December, 2019	3.45	16.11	79.00	58.00	6.70	105.8	3
January, 2020	3.00	13.91	82.00	66.00	4.80	178.2	10
February, 2020	5.40	18.22	82.00	58.00	7.30	6.40	3
March, 2020	7.12	19.00	77.00	65.00	6.10	235.80	13
April, 2020	11.86	24.50	64.00	48.00	7.00	92.80	8
May, 2020	15.42	27.80	59.00	50.00	8.20	157.00	13
June , 2020	17.23	28.22	71.00	68.00	7.10	259.40	18

*BSS = Bright Sunshine Hours **RD = Rainy Days

APPENDIX-III

Mean number of insects visiting on litchi in 2 minutes on a sunny day at peak bloom

	Hours of the day												
Location (Litchi)	**7-8 A.M.**	**8-9 A.M.**	**9-10 A.M.**	**10-11 A.M.**	**11-12 A.M.**	**12-1 P.M.**	**1-2 P.M.**	**2-3 P.M.**	**3-4 P.M.**	**4-5 P.M.**	**5-6 P.M.**	**6-7 P.M.**	**7-8 P.M.**
Saliana	13.20 ± 3.01	22.60 ± 6.10	34.80 ± 5.59	60.80 ±10.50	56.60 ±10.65	40.00 ± 9.72	25.60 ± 6.36	37.30 ±10.36	44.60 ±11.36	70.00 ±13.18	32.10 ±5.88	12.20 ± 4.61	0.00±0.00
Sulah	12.20 ± 4.61	20.00 ± 5.29	36.80 ± 7.35	73.10 ± 9.70	66.70 ±11.52	41.20 ± 10.28	25.20 ± 9.72	29.20 ±10.38	35.30 ±10.26	67.20 ±11.41	24.70 ±9.50	20.00 ± 7.51	0.30±0.67
Palampur	15.20 ± 7.91	20.20 ± 6.44	29.70 ± 9.43	57.00 ±13.34	49.00 ±13.22	46.00 ± 9.97	35.30 ±10.26	36.70 ±11.00	46.00 ± 9.97	53.70 ±11.49	45.20 ±10.69	17.50 ±10.97	3.00 ±3.16
Nagrota	22.40 ±12.53	24.00 ±11.89	30.60 ±10.50	61.70 ±11.00	53.00 ±18.02	45.10± 14.52	32.30 ± 9.98	33.70 ±8.97	35.10 ± 7.64	64.70 ±13.00	28.90 ± 4.77	12.90 ± 3.87	0.00±0.00
Location (Guava)	**7-8 A.M.**	**8-9 A.M.**	**9-10 A.M.**	**10-11 A.M.**	**11-12 A.M.**	**12-1 P.M.**	**1-2 P.M.**	**2-3 P.M.**	**3-4 P.M.**	**4-5 P.M.**	**5-6 P.M.**	**6-7 P.M.**	**7-8 P.M.**
Jachh	25.00 ± 6.43	24.30 ±6.00	36.60 ± 8.64	60.50 ±10.62	12.90 ± 3.87	28.00 ± 9.80	23.30 ±12.08	30.40 ±7.56	50.90 ±15.54	64.50 ± 7.89	36.60 ± 8.64	12.90 ± 3.87	1.00 ± 1.05
Palampur	25.80 ± 7.38	26.20 ±5.45	40.00 ± 6.94	51.60 ± 6.82	33.10 ± 5.17	36.00 ± 6.63	30.20 ±7.39	33.20 ±4.87	45.00 ±10.12	49.20 ± 7.35	36.60 ± 8.64	25.00 ± 6.43	1.80 ± 1.87
Bharwar	12.90 ±3.87	30.40 ±7.56	50.90 ±15.54	60.10 ±5.99	26.20 ±12.19	23.30 ±12.08	39.50 ± 6.43	40.20 ±6.07	57.80 ± 6.14	64.70 ±13.00	30.40 ±7.56	21.60 ±10.31	0.00±0.00

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B.Sc. (Hons.) Horticulture	2018	Dr.YSPUHF, Nauni, Solan (HP)	85.7	First	All compulsory courses for the award of B.Sc. (Hons.) Horticulture
M.Sc. (Ag.) Entomology	2020	CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur (HP)	79.2	First	Major discipline: Entomology Minor Discipline: Horticulture

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Publications: Nil

Visits abroad with duration and date of visit: Nil
Any other remarks: Nil