AUGMENTATION OF POLLINATION IN CULINARY MELON (*Cucumis melo* var. *acidulus* L. Naudin) WITH INDIAN BEE (*Apis cerana indica* Fab.)

by

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(2017-11-057)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"AUGMENTATION OF POLLINATION IN CULINARY MELON (*Cucumis melo* var. *acidulus* L. Naudin) WITH INDIAN BEE (*Apis cerana indica* Fab.)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"AUGMENTATION OF POLLINATION IN CULINARY MELON (*Cucumis melo* var. *acidulus* L. Naudin) WITH INDIAN BEE (*Apis cerana indica* Fab.)"** is a record of research work done independently by Ms. Aneetta M. R. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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Aneetta M. R.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

et al.	And other co workers
~	Approximately
@	At the rate of
cm	Centimetre
CRD	Completely Randomised Block Design
CD	Critical difference
^{0}C	Degree Celsius
g	Gram
ha	Hectare
h	Hour
KAU	Kerala Agricultural University
kg	Kilogram
μL	Microlitre
MT	Metric tones

m	Metre
mha	Million hectare
mm	Millimeter
min.	Minute
viz.	Namely
NS	Non significant
nos.	Numbers
%	Per cent
ha^{-1}	Per hectare
$min.^{-1}$	Per minute
q	Quintal
m^2	Square metre
sec.	Second
sp. or spp.	Species (Singular and plural)
i.e.	That is

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Introduction

1. INTRODUCTION

Pollination is the essential process that should take place for sustaining life forms in the earth. Pollination occurs when pollen is moved from anther to stigma of flowers within plant or between plants. Pollen is transferred by agents like honey bees, ants, bats, butterflies, moths, beetles, birds etc. which act as pollinators of crops. Globally 35 per cent of production is dependent on pollinators and 13 crops worldwide essentially require pollinators (Klien *et al.,* 2007). In India, out of the 160 mha cropped area, more than 55 mha is under bee pollinated crops and monetary value of this pollination service is estimated as Rs.3000 crores (Viraktamath *et al.,* 2013).

Often crop plants are benefited by pollination from feral pollinator populations such as honey bees, butterflies, beetles, solitary bees and bats. The pollination requirement of crops is hardly accomplished by these natural pollinators. In addition, agricultural intensification coupled with climate change adversely affected these natural pollinator fauna resulting in reduced population density. Complete pollinator loss would translate into a production deficit which ranges from 12 to 90 per cent in fruits and six per cent in vegetables according to current consumption levels (Klien *et al.*, 2007; Potts *et al.*, 2010). These necessitate relying on manged pollinators for enhanced yield in commercial agriculture. Pollinator scarcity is the main factor responsible for inadequate pollination which can be overcome by promoting beekeeping for pollination of agricultural crops (Devkota *et al.,* 2016).

Honey bees are essentially efficient pollinators of crops contributing to more than 80 per cent of total insect pollination (Thapa, 2006). They are capable of increasing yield in 96 per cent of animal-pollinated crops. Presence of branched hairs all over the body enables adherence of pollen from anther to body and its further transfer to stigma. Well-developed foraging activities and behaviour, increases the chance of pollen grains being transferred to the stigma. Branched hairs on the body surface and well developed foraging activities positions honey bees superior to all other pollinators (Bomfim *et al.*, 2016).

In India, native honey bee, *Apis cerana indica* Fab. is most commonly hived for commercial beekeeping. In addition to hive products, their role as potential pollinators of crops need to be exploited. They are efficient pollinators of many crops as they have coevolved with the flowering plants with modified morphological, anatomical and behavioural characteristics. Bees and their vital relationships with flowering plants occupy keystone positions in both natural and agricultural ecosystems (Viraktamath *et al.*, 2013). Introduction of bee hives to agroecosystem can boost production and thereby add up economic return from crops. Conservation of biodiversity is the added advantage of beekeeping for pollination management (Devkota *et al.,* 2016).

Cucurbits are one of the obligate crops which require honey bees for assuring optimum pollination. These cross pollinated vegetable group forms major part of vegetables produced in the country. Cucumber (*Cucumis sativus* L.) alone is being cultivated in an area of 76,000 ha with a production of 12,17,000 MT (GOI, 2017-18).

Melons are major group of genus *Cucumis*, and the species *C. melo* is a polymorphic taxon comprising a large number of botanical and horticultural varieties or groups. The culinary melon (*C. melo* var. *acidulus* L. Naudin) is a distinct group distributed and adapted well in humid tropics of southern India and known in variety of vernacular names *viz.*, vellari, melon, pickling melon, culinary melon etc. (Koli, 2013).

Pollination deficit in obligate entomophilus crops can even lead to yield losses. Pollination is often overlooked by farmers, as many rely on feral pollinator populations to provide pollination services to their crops and this is often not sufficient to meet the pollination requirements of crops (Siqueria *et al.*, 2011). Integrating the crop production with beekeeping and thereby augmenting pollinator fauna is the cheapest but an effective method to maximize crop yield.

Integration of beekeeping to agroecosystem for pollination enhancement requires knowledge on diversity of native pollinator fauna, foraging behaviour of bees with which pollination is augmented, floral biology of the crop and colony requirement for optimum pollination, which is the concept of planned bee pollination. Though reports on colony requirement of honey bees (*Apis mellifera* Linnaeus), for pollination in cucurbits are available, the results vary with location, crop and bee species, and native pollinators (Abrol, 2007). Pollination requirement vary even within cucurbits and researches on augmented pollination with Indian bee are scanty. Hence the present investigation entitled 'Augmentation of pollination in culinary melon (*Cucumis melo* var. *acidulus* L. Naudin) with Indian bee *Apis cerana indica* Fab.' is undertaken with following objective:

- To study the foraging behaviour of *Apis cerana indica* Fab. and to standardise the number of bee hives required for yield enhancement in culinary melon

Review of Literature

2. REVIEW OF LITERATURE

The literature pertaining to insect pollinator diversity, foraging behaviour of bees, floral biology, yield enhancement due to bee pollination and requirement of bee colonies for crops is reviewed here under.

2.1 IMPORTANCE OF BEE POLLINATION AND NEED FOR BEE POLLINATION IN CUCURBITS

Insect visits to blooms are known to mankind since ancient times. Though insects like ants, beetles and butterflies aid pollination, honey bees are regarded as credited pollinators of most of the cross pollinated crops (Deodikar and Suryanarayana, 1997). Honey bees are popularly called as "Angels of agriculture''. According to Verma *et al.* (1997), the value of honey bees in crop pollination is many times more than their value as producers of honey and other bee products. Thus bees are the foremost pollinators, where 30 per cent of all human food comes from bee pollinated plant species. According to Thapa (2006) more than 80 per cent of the total pollination activities are performed by insects and bee pollination alone accounts to nearly 80 per cent of the total insect pollination. Therefore, they are considered as the best pollinators.

Bee pollination enhances quality as well as quantity of crops. Pollination by bees is attributed to improved quality of fruits and vegetables in terms of fruit length, circumference and volume. In addition it also reduces unevenness of fruits. Fruit set also is enhanced by bee pollination. Oil seeds that are benefited by optimum bee pollination produce increased oil content. Better quality seeds in terms of number, thousand seed weight and germination per cent are achievable by optimum pollination by bees (Khan and Khan, 2004; Abrol, 2007; Sarwar *et al.*, 2008).

In cucurbits, pollen grains being large and sticky are unable to be easily wind borne and hence need an agent for pollen transfer. According to Garibaldi, *et al.* (2013) the most studied and utilized pollinators throughout the world for cucurbit crops are honey bees and they provide the greatest contribution to the pollination of cucurbits. According to Motzke *et al.* (2015), honey bee pollination alone accounted for 75 per cent of the yield of cucumber in Indonesia and was, hence, the most important driver of yield. Pollination requirement of crops vary with plant species and pollination deficits can lead to yield losses. Augmentation of natural pollination with domesticated bee species can significantly boost crop yield. *A. c. indica,* being the most common managed bee species in Indian subcontinent, it can be exploited as pollinator of crops for which foraging behaviour of the bee on concerned crop, floral biology and colony requirement need to be studied.

2.2 INSECT DIVERSITY IN CUCURBITS

Entomophilus crops are often visited by insects which can be pest, natural enemies, flower visitors and pollinators. Insect visitors of cucurbits including insects from major insect orders such as Hymenoptera, Lepidoptera, Coleoptera, Hemiptera and Diptera have been reported by many authors.

2.2.1 *Insect Pests*

The melon fly with its worldwide distribution and India as native home, damages over 81 plant species among which cucurbits are most preferred (Dhillon *et al.*, 2005). Melon fly (*Bactrocera cucurbitae* Coquillet) and beetles caused 73.83 per cent and 70.00 per cent damage respectively on cucumber in West Bengal (Ghule *et al.*, 2014). Vinutha *et al.* (2017) recorded the insect fauna of *C. melo* in Karnataka. The diverse insect pest has been recorded from Coleoptera (31.00 %), Hemiptera (25.00 %), Lepidoptera (13.00 %), Diptera (10.00 %), and Thysanoptera and Orthoptera (3.00 % each). The major pest observed were fruit flies (*B. cucurbitae, B. correcta*) and bugs (*Spilostethus hospes* Fabricius, *S. pandurus* Fab.)

The damage caused by tobacco caterpillar (*Spodoptera litura* Fab.) to cucumber (*C. sativus*) in Punjab was accounted as five per cent by Kaur *et al.* (2010). *Epilachna dodecastigma* (Wied.), *Aulacophora fovecollis* (Lucas), *Diphania indica* (Saunders), *B. cucurbitae* and *Bemisia tabaci* (Gennadius) were recorded as pest of pointed gourd (*Trichosanthes dioica*) by Barma and Jha (2013). Sunil *et al.* (2017) reported seasonal incidence of beetles (*A. foveicollis* and *Luperomorpha vitatta* Duviver) in bitter gourd (*Momordica charantia* L.) with a mean of 0.07 and 0.05 insects per plant in kharif and rabi respectively. Incidence of these pests in Bangalore was positively correlated with minimum temperature and maximum RH both during kharif and rabi.

2.2.2 *Natural Enemies*

The coccinellid beetles *viz.*, *Menochilus sexmaculatus* Fab., *Synharmonia octomaculata* Fab., *Micraspis crocea* (Mulsant), spiders (*Oxyopes javanus* and *Lycosa pseudoannulata*) and parasitoids (*Apanteles* sp., *Chrysocharis johnsonii*) were recorded as natural enemies of pests of culinary melon by Jangaiah (2007) in Kerala. Natural enemies observed on bitter gourd in Bangalore were recorded by Sunil *et al.* (2017). The insect fauna mainly comprised of five species of coccinellid beetles *viz.*, *Chilocorus melas* (Weise), *Coccinella septempuntata* L., *Scymnus* sp, *Coccinella transversalis* Fab. and *Cheilomenes sexmaculata* Fab. Vinutha *et al.* (2017) observed the common predators, *C. sexmaculata* (Fab.), *C. transversalis* and *Illeis cincta* (Fab.) on *C. melo*. The other natural enemies recorded include a parasitoid, *Brachymeria* sp. and two spiders.

2.2.3 *Pollinators*

Major pollinators of water melon in Southern Colarado, USA were recorded by Brewer (1974) which comprised *Melissodes bimaculata (*Lepeltier), *Florilegus condignus* (Cresson), *Lasioglossum sp., Agapostemon texanus* (Cresson)*, Halictus ligatus* (Say) *and H. confusus* (Smith). *M. bimaculata* was the dominant pollinator. Melendez-Ramirez (2002) reported pollinator fauna of cucurbits in Mexico. The pollinators belonged to six family, 29 genera and 58 species. Feral pollinators of pumpkin in USA were observed by Walter and Taylor (2006) which consist of bumblebees (*Bombus* sp.), carpenter bees (*Xylocopa* sp.), honey bees and squash bees (*Peponapis pruinosa* (Say)).

Pateel (2007) recorded pollinator fauna of cucumber (*C. sativus*) consisting of 12 species in three orders Hymenoptera, Diptera and Lepidoptera. Hymenopteran insects were major with nine species followed by Dipteran (2) and Lepidopteran (1) insects. Insect pollinator diversity on cucumber in Bangalore was reported by Rubina (2010) which comprised of 28 species belonging to Hymenoptera (20), Lepidoptera (4), Diptera and Coleoptera (each with two species). Hymenopterans were dominant (84.88 %) compared to other pollinators (15.11 %). Dorjay *et al.* (2017) remarked that cucumber flowers attracted wide varieties of insects belonging to four orders, 12 families, 17 genera and 21 species.

Gautam and Kumar (2018) reported pollinators of ridge gourd (*Luffa acutangangula*). Total of eight insect species visited ridge gourd flowers, *viz.* five Hymenopterans, two Dipterans and one belonged to Odonata. *Apis mellifera* L., *A. dorsata* F., *A. florea* F., *Xylocopa fenestrata* F. and *Polistes* sp. were found to be most frequent pollinators. Raeesa (2018) claimed that *A. c. indica* and *T. iridipennis* (Smith) were the major pollinators of culinary melon. The other pollinators comprised *A. c. indica, A. dorsata, T. iridipennis*, *A. foveicollis*, *A. leweisii* (Baly), *Xylocopa* sp., *Luperomorpha* sp., and *Lampides* sp.

2.2.3.1 Relative Abundance

Pollinator fauna on bittergourd in Hyderabad, was recorded by Subhakar *et al.* (2011) in which Hymenopterans were major pollinators (87.56 %). The abundance of other pollinators was recorded as Lepidoptera (4.68 %), Orthoptera (7.92 %), Diptera (5.81 %) and Coleoptera (1.95 %). Relative abundance of pollinators on culinary melon in Kerala was reported by Boli (2013). The populations of *A. cerana, A. mellifera* and *T. iridipennis* was recorded as 5.80, 5.26 and 3.40 bees m^{-2} 5 min^{-1} and thereby concluded that *A. cerana* was dominant pollinator in culinary melon. Dorjay *et al.* (2017) confirmed that honeybees were the most predominant (74.00 %) pollinators on cucumber. The other pollinators observed were *Xylocopa fenestrata, X. pubescens,* *Pithitus smaragdula, Halictus* spp., *Lasioglosium* spp., *Anthophora* spp. and *Andrena* spp.

Jyothi (2003) recorded peak population of *A. cerana* on cucumber as 6 bees m^{-2} 5 $min.^{-1}$ flowers during 1000 to 1100 h. Studies on abundance of pollinators on oriental pickling melon in Kerala by Jangaiah (2007) revealed that *A. cerana* was dominant pollinator with mean populations of 4.40 bees m^{-2} 5 min^{-1}. Pateel (2007) reported relative abundance of pollinators on cucumber in Karnataka in which *A. florea* was dominant (42.00 %) followed by *A. cerana* (24.00 %) and *Coelioxys* sp. (20.00 %). Insect pollinators of cucumber in Hariyana were studied by Hanh (2008). The insect species were recorded from all major insect orders *viz.,* Hymenoptera (12), Lepidoptera (6), Diptera (3), Hemiptera (2), and Coleoptera (1). *Halictus* sp. (2.69 bees m^{-2} $min.^{-1}$) was predominant pollinator followed by *A. dorsata* (0.78 bees m^{-2} min^{-1}). Deka (2014) confirmed that *A. cerana* (51.04 %) was predominant pollinator on cucumber in Assam followed by *A. mellifera* (12.35 %), *Xylocopa* sp. (9.28 %) and *A. dorsata* (6.96 %). Butterflies, ants and wasps were also observed.

2.2.3.2 Foraging Behaviour

Studies on the bee botany and its foraging behaviour are essential for utilization of bees in crop yield enhancement.

Apis cerana

Verma and Partap (1994) recorded foraging rate of *A. c. indica* on cabbage and cauliflower as 5-8 flowers $min.^{-1}$ in Nepal. Peak foraging time was observed at 1100 h and 1300 h in cauliflower and cabbage respectively. According to Panda *et al.* (1995) the predominant visitor of niger in Orissa was *A. c. indica* with maximum bee activity during 1000 to 1100 h. Singh *et al.* (2006) observed *A. cerana* as superior pollinator on *Brassica napus* in Madhya Pradesh with a peak foraging rate of 20.92 flowers $min.^{-1}$ at 1200 h. Rajkhowa and Deka (2013) claimed that maximum (264.37) and minimum (135.85) flower visit per trip by *A. cerana* was during 1000-1100 h and 1300-1400 h respectively in Assam.

Premila *et al.* (2014) reported that the duration of foraging of *A. cerana* on culinary melon under Kerala conditions was eleven hours with a foraging rate of 4.77 flowers min.$^{-1}$. According to Kumari (2014) foraging rate of *A. cerana* on *B. napus* and *B. juncea* in Punjab ranged between 3.2 to 13.9 flowers min.$^{-1}$ with peak activity between 1000-1200 h. Proportion of pollen gatherers was recorded as 7.80 to 19.20 per cent. Comparative study on foraging behaviour of *A. cerana* and *A. mellifera* by Ahmad *et al.* (2017) revealed that the former was superior with foraging rate of 10.11, 10.03 and 8.86 flowers min.$^{-1}$ in Srinagar, Shopian and Saller respectively.

Verma and Partap (1994) recorded time period of individual foraging trips of *A. c. indica* in Nepal as 26.90 min. in cauliflower and 23.90 min. in cabbage. Foraging speed was reported as 4.3 to 6.7 sec. during the day in both crops.

Dominant pollinating agent in water melon was assessed as *A. cerana* with a foraging speed of 1.40 to 6.90 sec. by Rao and Suryanarayana (1988). According to Eswarappa (2001) *A. cerana* spent 7.59 sec on chow-chow plants both in open and caged conditions. Time spent on staminate and pistillate flowers of cucumber by *A. cerana* was recorded as 38.12 sec. and 35.31 sec. by Prakash (2002). The bee visitation to cucumber (*C. sativus*) flowers in Assam was observed from 0700 to 1600 h by Islam and Deka (2009). The peak period of activity was recorded between 0900 to 1000 h. Maximum time spent on flowers was observed during 0800 to 0900 h (8.56 sec.). Foraging behaviour of *Apis* spp. on apple flowers was studied by Joshi and Joshi (2010) at Uttarakhand. *A. cerana* foraged for longer period of the day (12.47 h) with peak at 1200 h. Commencement of foraging time was 6.09 h while cessation was observed at 18.56 h. Study confirmed that *A. cerana* was found to be efficient pollinator for subtropical region.

Rajkhowa and Deka (2013) recorded maximum (3.64 sec.) and minimum (1.31 sec.) foraging speed of *A. c.* on redgram during 0900-1000 h and 1300-1400 h respectively in Assam. The time spent by bees on culinary melon during peak activity period (1000-1100 h) was observed as 5.08 sec. (Boli, 2013).The mean foraging speed of *A. cerana* on culinary melon was recorded as 5.38 sec., which positioned it in highest rank for pollination efficiency in culinary melon (Premila *et al.*, 2014). Foraging behaviour of *A. cerana* on apple blooms in three locations at Kashmir valley was recorded by Ahmad *et al.* (2017). *A. cerana* rendered long duration of foraging which was recorded as 13.1, 12.26 and 12.11 h at Srinagar, Shopian and Saller respectively. Mean foraging speed was 6.24 sec. According to Raeesa (2018) there was no significant difference in time spent by *A. cerana* on staminate and pistillate flowers of culinary melon which was recorded as 3.54 sec.

Foraging activity of *A. cerana* under tropical conditions of Karnataka was reported by Jyothi (2003) in which intensity of *A. cerana* was 24.30 to 26.70 bees m^{-2} $min.^{-1}$ with peak at 1300 h and lowest population (0.00 bees) at 1800 h were observed in niger. Rajkhowa and Deka (2013) studied foraging activity of *A. cerana* on redgram wherein maximum intensity of bees was 11.28 bees m^{-2} $min.^{-1}$ during 1000-1100 h and lower intensity was 3.04 bees m^{-2} $min.^{-1}$ during 1300-1400 h in Assam. Painkra (2014) studied foraging behaviour of *A. c. indica* in Raipur. Maximum bees were visiting on niger which was 66.06 bees m^{-2} $5min.^{-1}$ at 1100 h. The foraging intensity of *A. cerana* on culinary melon was recorded as 11.40 bees m^{-2} $min.^{-1}$ in Kerala by Premila *et al.* (2014). Kumari *et al.* (2014) recorded highest foraging intensity of *A. cerana* on *B. napus* as 2.80 bees m^{-2} $min.^{-1}$. Kumari *et al.* (2016) ranked *A. cerana* as second predominant pollinator of *B. napus* with a foraging intensity of 1.65 bees m^{-2} $min.^{-1}$. Peak activity was observed at 1200 h of the day. Raeesa (2018) recorded the number of bees visiting culinary melon (*C. melo*) as 2.4 bees m^{-2} $min.^{-1}$ under Kerala conditions.

Apis mellifera

In *B. napus, A. mellifera* was observed to be foraging at the rate of 19.57 flowers min.$^{-1}$ as recorded by Singh *et al.* (2006). *A. mellifera* was observed to be superior to other bee pollinators and was foraging intensively at 12.00 h in Madhya Pradesh.

Singh *et al.* (2014) reported foraging activity of *A. mellifera* in Punjab. It was observed that maximum blooms of *C. melo* were visited during 0900-1000 h (6.93 flowers min.$^{-1}$) and 0600-0700 h (6.46 flowers min.$^{-1}$) of the day which were statistically on par. According to Kumari (2014) *A. mellifera* ranked as the most efficient pollinator on *B. napus* and *B. juncea* in Punjab. *A. mellifera* recorded maximum foraging rate of 11.10 flowers min.$^{-1}$ at 1200 h. Peak activity of pollen gatherers were observed between 1000-1200 h and their proportion was recorded as 12.50-31.90 per cent.

Foraging behaviour of *A. mellifera* on cauliflower was studied by Singh *et al.* (2016) at three villages, Hariharpur, Rajapakar and Chakwara in Bihar. Highest foraging rate observed was 7.25 flowers min.$^{-1}$ in Hariharpur followed by 7.4 flowers min.$^{-1}$ and 5.45 flowers min.$^{-1}$ in Chakwara and Rajapakar respectively. Lalita and Kumar (2017) recorded foraging rate of *A. mellifera* on different pumpkin (*C. moschata*) cultivars at Hariyana. Foraging rate was recorded as 4.16 flowers min.$^{-1}$ and 4.19 flowers min.$^{-1}$on cultivars C-1106 and C-1076 respectively.

Foraging behaviour of *Apis* spp. on apple flowers was studied by Joshi and Joshi (2010) at Uttarakhand. *A. mellifera* foraged for a period of 12.11 h with peak at 1400 h. Bees commenced foraging on 6.17 h and ceased activity on 18.38 h. Foraging speed of *A. mellifera* on cauliflower was studied by Singh *et al.* (2016) at three villages, Hariharpur, Rajapakar and Chakwara. It was observed as 5.45, 5.92 and 4.54 sec. in the above three villages respectively.

Comparative study on foraging behaviour of *A. cerana* and *A. mellifera* was conducted by Ahmad *et al.* (2017) on apple blooms in three locations at

Kashmir valley. Foraging speed of *A. mellifera* was found to be higher (8.44 sec.). The mean foraging speed of *A. mellifera* on pumpkin varied from 7.15 to 7.63 sec. on cultivars C-1076 and C-1106 respectively at Hariyana (Lalita and Kumar, 2017). Foraging rate was recorded as 4.16 flowers min.$^{-1}$ and 4.19 flowers min.$^{-1}$ on cultivars C-1106 and C-1076 respectively. The duration of bee visit at different hive density to hermaphrodite and male flowers of melon was recorded by Riberio *et al.* (2017). The mean foraging speed was observed as 16, 9.82, 18.54 and 33.11 sec. on former at hive densities 0, 1, 2 and 3 respectively. Mean duration of bee visit on latter was recorded as 4.34, 5.84, 5.13 and 5.63 sec. with varying hive densities 0, 1, 2 and 3 respectively.

Brar *et al.* (2010) reported the foraging intensity of *A. mellifera* on radish (*Raphanus sativus*) wherein intensity of bees was significantly higher (1.94-2.13 bees m^{-2} min.$^{-1}$) at 20 m distance beyond which the intensity decreased. Singh *et al.* (2014) reported that maximum foraging intensity of *A. mellifera* was during 0900-1000 h of the day which was recorded as 3.28 bees flower $^{-1}$ min.$^{-1}$. The pollen foragers were observed as top wrokers on *C. melo* and their proportion was recorded maximum (18.00 %) during 0600 to 0700 h. According to Kumari *et al.* (2016) *A. mellifera* was predominant pollinator of *B. napus* in Punjab. The peak activity was recorded at 1200 h of the day with a foraging intensity of 1.95 bees m^{-2} min.$^{-1}$.

2.2.4 Influence of Meteorological Factors

Hari *et al.* (1994) reported that floral visit of *A. c. indica* was positively correlated with temperature. Kumar *et al.* (2002) stated that temperature and relative humidity has influence on number of bees visiting flowers. Highest number of bees was observed at maximum mean temperature of 18.03^{0}C and lower relative humidity of 60 per cent. According to Mattu *et al.* (2006) temperature positively influenced foraging activity of both *A. cerana* and *A. mellifera* in pear flowers in Shimla. Relative humidity was found to have negative correlation with bee activity. Joshi and Joshi (2010) studied the influence weather parameters on foraging activity of pollinating insects at Uttarakhand. At temperatures below 20 to 22^{0}C least population of bees foraged on flowers. Foraging activity reduced during high humidity whereas it was ceased completely during rain. Rajkhowa and Deka (2013) reported positive relationship between foraging behaviour of honey bee and temperature while non-significant negative relationship was observed with relative humidity. The study conducted by Dorjay *et al.* (2017) revealed the influence of temperature and relative humidity on bee activity wherein bee population was positively correlated with former and negatively correlated with latter. Gautam and Kumar (2018) observed that temperature and mean population of pollinator species were positively correlated while negative correlation was found with relative humidity indicating that temperature plays an important role on activity of insect pollinators.

2.3. INFLUENCE OF FLORAL CHARACTERS ON BEE ACTIVITY

2.3.1 Flower Colour

Stanton (1987) observed response of pollinator species to petal colour polymorphism in radish (*Raphanus sativus*), wherein honey bees preferred yellow or white flowers over bronze at California. Syrphid flies were observed as frequent visitors next to bees which preferred pink flowers. According to Sutherland *et al.* (1999) both male and female hover fly, *Episyrphus balteatus* tend to show preferences for yellow and blue artificial flowers.

2.3.2 Sex of Flower

Bee visit may vary with sex of flower. Klinkhamer and de Jong (1990) reported that in viper's bugloss (*Echium vulgare*), male flowers producing abundant nectar were visited by more pollinators than female flowers. Gonzalez *et al.* (1995) reported that female flowers of *Lavandula stoechas* contained twice the volume of nectar of male flowers. Honey bees (*A. mellifera*) preferred inflorescences with relatively greater number of both male and female flowers which was the morphological cue for bees. Goulson (1999) claimed that sexual phases as well as most rewarding sexual form of the flowers could be distinguished by pollinators.

Stanton and Young (1991) reported that pollinator visitation influenced male and female reproduction and it varied with pollinator taxa. Paternal success significantly increased by small native bee visits, while male fitness was reduced by honey bees. Duffield *et al.* (1993) remarked that in french lavender (*L. stoechas*), *A. mellifera* preferred inflorescence with higher number of opened flowers, containing abundant nectar volume and sugar concentration which was the morphological cue for bees. Negative relationship between corolla length and nectar and sugar concentration was observed.

2.3.3 Other Floral Parameters

Shrivastava and Shrivastava (1991) remarked that stamens in majority of cucurbits were synandrous (stamens united through both anther and filaments). Numbers of stamens were generally five and reduction of stamens from five to three was result of coevolution of plant and pollinator. Stamens of all *Cucumis* sp. was recorded as syngenesious type wherein anthers are united together into a tube and filaments are free. Satheesha (2010) studied floral biology of cucumber wherein length of corolla tube of male and female flowers were recorded as 3.40 cm and 3.50 cm respectively. Stamens were five with a length of 0.50 cm. Length of ovary was recorded as 2.80 cm. Anthesis was at 0600 h and flowers remained opened for single day.

Studies conducted at All India Coordinated Research Project (AICRP on HB & P, 2013) on floral biology of culinary melon revealed that stigma was receptive only on the day of anthesis. Average size of male flowers was 3.37 cm with a stamen length of 4.89 mm and 1.35 mm gap between bases of stamen. Average size of female flowers was 3.80 cm and pistil length was 1.35 cm. Verma (2017) observed anthesis in various cultivars of cucumber in Solan and reported that anthesis initiated at 0600 h and continued up to 0800 h irrespective of cultivars. Stamiante flowers opened first followed by pistillate flowers. Stigma receptivity was one day.

2.4. STANDARDISATION OF BEE HIVES

Several reports are available on the visits of honey bees to cross pollinated vegetable crops. Bee pollination enhances fruit quality in terms of fruit weight and size and reduces fruit drop. The production depends on insect pollination in a direct sense only in vegetables where the fruit is eaten; hence the role of pollinators for fruit set in cucurbit vegetables is highly imperative.

2.4.1 Fruit and Seed Quality

Studies conducted by Premila *et al.* (2014) revealed significance of bee pollination in yield enhancement of culinary melon. Percentage fruit set was recorded high in bee pollinated plots (71.62) in which deformed fruits were also minimum (36.17). Open pollinated plots recorded lower fruit set (41.29 %) and higher deformed fruits (68.84 %). Kenchannavar (2016) recorded the effect of bee visits in fruit quality of sponge gourd (*Luffa cylindrica*) in Bangalore. Fruit quality was enhanced by 20 visits by *A. cerana* which resulted in higher fruit weight (340.20 g) and size (30.12 cm) followed by 15 visits (322.80 g and 30.29 cm). No fruits were set in the absence of bee visits, one bee visit and five visits by *A. cerana.*

Effect of *A. mellifera* visit on cucumber fruit quality at Oka was reported by Gingras *et al.* (1999). The fruit set was recorded as 28 per cent in bee pollination. Size of fruits was enhanced by bee visitation which resulted in longer (22.90 cm) and larger (circumference-17.00 cm) fruits in open pollinated crops against caged plots with bees (length-22.40 cm, circumference-16.60 cm). Pollinator excluded plots produced still smaller fruits (length-22.20 cm, circumference -16.10 cm). Fruit size was found to have positive and significant correlation with pollination rate which accounted for 19 per cent of the variation in circumference. Nicodemo *et al.* (2009) reported that minimum of 16 visits by

A. mellifera on pumpkin significantly enhanced fruit quality in terms of fruit set, length and weight in Brazil which were recorded as 55.00 per cent, 160.70 mm and 98.10 mm respectively in 2001 and 45.00 per cent, 188.00 mm and 115.00 mm in 2002.

Hossain *et al*. (2018) compared open pollination with pollinator exclusion conditions in fruit quality of cucumber in Bangladesh. Open pollination resulted in higher fruit set (61.92 %) and lower mishappen fruits (20.25 %) against significantly lower fruit set (48.96 %) and higher mishappen fruits (24.35 %) in pollinator excluded plots. Fruit size was higher in open pollination (length-26.50 cm, diameter -26.80 cm) than plots without bees (length-21.80 cm, diameter-23.90 cm).

According to Verma and Partap (1994) germination of seeds in cabbage and cauliflower increased by 12.00 per cent and 28.00 per cent respectively due to *A. cerana* pollination. Devkota *et al.* (2003) confirmed that quality of broccoli seeds could be enhanced by honey bee pollination. Augmented pollination with *A. cerana* and *A. mellifera* resulted in 480.11 per cent and 479.32 per cent increased seed set respectively over the control plot without insects in Nepal. Also significantly higher thousand seed weight was recorded from *A. cerana* (3.750 g) and *A. mellifera* (3.637 g) pollinated seeds over naturally pollinated seeds (3.207 g). Rubina (2010) remarked that bee pollination (*A. cerana*) influenced seed quality of cucumber which was attributed to higher germination (88.26 %). Enhanced number of seeds per fruit and test weight were recorded as 425.41 and 4.11g respectively. Bhagawati and Rahman (2015) claimed the effect of *A. cerana* pollination on quantitative and qualitative parameters of sesame (*Sesamum indicum* L.) in Assam. Both oil content as well as moisture content were found to be higher in bee pollinated treatments and were recorded as 54.17 per cent and 10.18 per cent respectively.

In South Eastern Colarado, water melon plants receiving *A. mellifera* visitation produced good quality seeds with 98 per cent germination which was highest (Brewer 1974). Singh *et al.* (2016) reported role of honey bee (*A. mellifera*) pollination for quality seed production of cauliflower in Bihar which produced 52.80 pods per panicle compared to open pollination which yielded 46.20 pods per panicle. Seeds per pod were increased by 12.25 per cent while thousand seed weight recorded 9.09 per cent increase.

2.4.2 Fruit and seed yield

Premila *et al.* (2014) recorded maximum single fruit weight of 2.92 kg in *A. cerana* pollinated culinary melon. The mean number of seeds per fruit (1110.20) as well as thousand seed weight (20.60 g) were also high in bee pollinated plots.

Effect of honey bee visit on cucumber (*C. sativus*) yield at Oka was reported by Gingras *et al.* (1999). Open as well as caged plots with *A. mellifera* resulted in higher rate of pollination which was recorded as 53.60 per cent and 40.90 per cent against caged control plots without insects (12.80 %). Fruit weight was recorded as 316.90 g and 294.30 g in open and caged plots with bees respectively. Walter and Taylor (2006) reported that honey bee pollination (*A. mellifera*) enhanced fruit and seed yield of pumpkin in USA. Increase in fruit weight of *Cucurbita pepo, C. moschata* and *C. maxima* were recorded as 26.00 per cent, 70.00 per cent and 78.00 per cent respectively. Augmented pollination with *A. mellifera* resulted in higher average yield of 31,547 kg against 22353 kg in plots without bee colonies.

Role of insect pollination in cucumber yield in Solan was studied by Thakur (2007). Maximum fruit weight was obtained (1184.50 g) due to bee pollination while minimum was produced by open pollination (982.60 g). Sarwar *et al.* (2008) confirmed that honey bee (*A. mellifera*) pollination enhanced quantity as well as quality of cucumber which consequently maximized fruit set and yield in Islamabad. Maximum fruit set (85.40 %) was observed in open plot followed by cage pollination with bees (81.28 %) while plots excluded from pollinators accounted 12.60 per cent fruit set.

Rai *et al.* (2008) recorded the influence of honey bee pollination in cucumber yield in Karnataka. The crop under caged pollination with bees

(*A. mellifera*) yielded maximum (236.25 q ha^{-1}) against caged control without bees (37.26 q ha^{-1}). Under open field condition, the crop yielded 191.35 q ha^{-1}. The percentage increase in caged plots with bees was 24.46 per cent over the crop grown under open field condition and 534.06 per cent than the yield from caged control without bee hive. Role of *A. mellifera* in pollination of *C. melo* was studied by Singh *et al.* (2014). Bee pollinated crops recorded significantly higher fruit weight (395 g) compared to open pollination (352 g) and hand pollination (331 g). Kumari (2014) claimed increased seed yield in *B. napus* (49.65 %) and *B. juncea* (43.46 %) in Punjab due to bee (*A. mellifera*) pollination.

Walter and Taylor (2006) reported the effect of honey bee pollination on seed yield of pumpkin in USA. Number of seeds increased by 61 per cent and seed weight increased from 22 per cent to 100 per cent due to bee pollination. Painkra (2014) recorded significantly highest seed yield (513.00 kg ha^{-1}) in niger in Raipur due to bee pollination.

2.4.3 Requirement of Bee Hives

According to Mussen (1997) 2.5 colonies ha^{-1} are required for optimum pollination of cucurbits in California. Further, increasing the number of colonies from one to two or three per acre can result in high quality marketable crop with 100 more crates per acre than the usual 50 crates per acre (125 ha^{-1}). Sabbahi *et al.* (2005) reported 46 per cent increase in seed yield of canola at Canada, when plots were augmented with three bee hives (*A. mellifera*) per hectare. It also resulted in increased pod set by 77 per cent. Manning and Wallis (2005) remarked that pollination by *A. mellifera* @ one hive per hectare enhanced seed yield (2.19 tons ha^{-1}) up to 200 m distance from bee hive and yield reduced beyond 200 m distance from bee hive. Duran *et al.* (2010) reported that augmentation of rapeseed fields @ 6.5 bee hives ha^{-1} enhances seed yield by 5.34 per cent in Chile.

According to Brar *et al.* (2010) five colonies of *A. mellifera* (10 bee-frame strength) per hectare were required for maximizing the seed yield of radish. Kumari (2014) reported that maximum benefit of bee pollination in *B. napus* and

B. juncea were recorded up to 42.50 m distance from *A. mellifera* colony and accordingly two colonies each of 10 bee-frame strength ha^{-1} were suggested for maximizing pollination benefits. Bhagawati and Rahman (2015) reported the effect of *A. cerana* pollination on quantitative and qualitative parameters of sesame (S. *indicum*) in Assam. It was found that thousand seed weight, per cent of seed set and germination were higher due to bee pollination compared to open pollination and pollinator exclusion. Augmented pollination with seven hives ha^{-1} recorded highest yield which was accounted as 835 kg ha^{-1}.

Materials and Methods

3. MATERIALS AND METHODS

The study on 'Augmentation of pollination in culinary melon (*Cucumis melo* var. *acidulus*) with Indian bee (*Apis cerana indica*)' was carried out at farmers' field in Kulathoor, Thiruvananthapuram and Department of Agricultural Entomology, College of Agriculture, Vellayani during 2017-2019. The objectives were to study foraging behaviour of *A. c. indica* and to estimate the requirement of bee hives for yield enhancement in culinary melon. The materials used and methods employed for the study is described here under.

3.1. INSECT POLLINATOR DIVERSITY AND FORAGING BEHAVIOUR OF DOMINANT POLLINATOR

Preliminary observations on pollinator diversity as well as the relative abundance of insects were carried out for assessing dominant pollinator and to study its foraging behaviour. These observations were conducted at farmer's field at Thiruvananthapuram on standing crop of culinary melon during summer season. All the observations regarding pollinator diversity and foraging behaviour were made at different hours of the day (0600–0700 h, 1000–1100 h, 1400–1500 h and 1700–1800 h) at weekly intervals during peak flowering period (AICRP, 2013).

3.1.1 Insect Fauna on Culinary Melon

Insect visitors of the crop were observed at weekly intervals during flowering period. Recorded insects were categorised as pest, natural enemies, flower visitors and pollinators. An insect was considered as pollinator if the insect visited flowers and made contact with reproductive parts (stamen or stigma) of the flower (Bomfim *et al.*, 2016). Insect pollinators of the crop were observed at different time periods as mentioned under paragraph 3.1.

3.1.1.1 *Relative Abundance*

Relative abundance was determined by observing insect pollinators in an area of one square metre at different hours as mentioned under paragraph 3.1. It was recorded as number of insects visiting flowers for five minutes from randomly selected one square metre area and represented as mean number of insects m^{-2} 5 $min.^{-1}$. Further, dominant pollinator of culinary melon in the experimental site was determined based on these data. The insect which recorded maximum abundance at all time periods was assessed as dominant pollinator.

3.1.2 Foraging Behaviour of Dominant Pollinator

For studying the foraging behaviour, observations on foraging time, foraging rate, foraging speed, foraging intensity, foraging mode and proportion of pollen and nectar gatherers were recorded.

3.1.2.1 *Foraging Time*

Timings of commencement and cessation of flight activity in a day was indicated as foraging time. The times when bees started foraging on flowers of culinary melon in the morning and ceased their foraging in the evening were recorded and that time period was expressed as foraging time.

3.1.2.2 *Foraging Rate*

Number of flowers visited by single bee for one minute was recorded at varying time periods as mentioned under paragraph 3.1. During each observation period 10 bees were observed for foraging rate. Foraging rate was expressed as average number of flowers visited per unit time.

3.1.2.3 *Foraging Speed*

Time spent on single flower by bee was recorded at two hour interval from 0600 h to 1800 h with the help of stop watch. Ten bees were observed for foraging speed at each observation period. The duration between first alighting on flower and the time at which bee leaves the flower was recorded and foraging speed was expressed as average time spent on single flower. Time spent on both male and female flower was recorded separately.

3.1.2.4 *Foraging Intensity*

For recording foraging intensity, number of bees visiting blooms in four randomly selected one square meter area was observed. These observations were made at every two hour intervals throughout observation day. Foraging intensity was expressed as average number of bees visiting blooms m^{-2} $min.^{-1}$

3.1.2.5 *Foraging Mode*

Foraging mode was determined by observing on mode of alighting of foragers on flowers. Bees alighting directly on top of stamen were considered as top workers while those alighting on petals at base of stamen were regarded as side workers. Ten bees were observed at each observation period for their foraging mode.

3.1.2.6 *Proportion of Pollen Gatherers and Nectar Collectors*

The per cent data on proportion of pollen gatherers and nectar collectors among the dominant pollinator population were worked out. Ten foraging bees on flowers were observed at different hours of the day as mentioned under paragraph 3.1. Those bees which carried pollen load on corbiculae were considered as pollen gatherers while other foragers which inserted their proboscis but not carried corbicular pollen load were regarded as nectar collectors. Those foragers which inserted their proboscis and carried pollen load were recorded as pollen and nectar collectors.

3.1.2.7 Influence of Weather Parameters on Foraging Behaviour

Influence of weather parameters such as temperature and relative humidity on foraging behaviour was studied. These parameters were recorded at each of time periods mentioned under paragraph 3.1using thermohygrometer.

3.1.2.8 Statistical Analysis

Collected data on foraging behaviour was analysed using Completely Randomised Design. The data was subjected to square root transformation wherever required. Statistical analysis was performed using the software WASP version 2.2. Influence of temperature and relative humidity on foraging behaviour was assessed by correlation studies.

3.2. FLORAL BIOLOGY OF *C. melo* var. *acidulus* AND PROBOSCIS LENGTH OF BEES

For studying floral biology of culinary melon, ten male and female flowers each of same size and vigour were selected at random. Proboscis length of bees was also examined to assess relationship between flower structure and proboscis length.

3.2.1 Flower Spread

For measuring flower spread, ten male and female flowers, each of similar age and size were selected. Flower spread was measured as distance between terminal points of diagonally opposite petals using scale and expressed as average flower spread.

3.2.2 Stamen Length

Ten male flowers, each of similar age and size were selected. Petals were excised and exposed stamens were observed under microscope. Stamen length was measured by using of image analysing software and expressed as average stamen length.

3.2.3 Basal Gap between Stamens

The above mentioned procedure (3.2.2) was carried out to measure basal gap between stamens. Distance between bases of stamens was measured as basal gap using image analysing software.

3.2.4 Pistil Length

Ten female flowers were selected as detailed under paragraph 3.2. Length of pistil was taken as distance from base of ovary to top surface of stigma. It was measured using vernier calipers and expressed as average pistil length.

3.2.5 Stigma Receptivity

For assessing stigma receptivity, female flower buds which will open on next day were tagged. Opened flowers were observed for receptivity for four days. Yellowish green stigma shining with stigmatic exudation was considered as receptive. Dull, dried and dark brown coloured stigma was considered as non-receptive.

3.2.6 Length of Proboscis

Ten bees were collected, killed and proboscis was excised. It was examined under microscope to measure proboscis length. Length of proboscis was measured as distance from mentum to flabellum

3.2.7 Statistical Analysis

The recorded data on floral biology were analysed using statistical parameters like mean, standard deviation and coefficient of variation.

3.3 STANDARDISATION OF NUMBER OF BEE HIVES (*A. c. indica*)

3.3.1 Lay Out of Experiment

Culinary melon (*C. melo* var. *acidulus*) was raised at farmer's field Thiruvananthapuram during February to April of 2019 (Plate 1). The seeds were purchased from Instructional Farm, Vellayani. All cultivation practices except spraying of pesticides were followed as per recommendations of package of practices of Kerala Agricultural University (KAU, 2016). The experiment was carried out as detailed below :

Design	: CRD
Variety	: KAU Vishal
Plot size	: 1 acre
Spacing	: 1.5 x 2 m
No. of plants per pit	: 2
No. of treatments	: 4
No. of replications	: 4

At 10 per cent flowering, a six frame strength colony of *A. c. indica* was installed at centre of plot (Plate 1). The radial distances 10, 20, 30 and 40 m from bee hive were marked and were considered as treatments (Figure 1). Four plants (replications) of similar size and vigour were selected as observational plants for each of the marked distances. Foraging intensity and yield parameters as detailed below were recorded from these observational plants. A control plot without bee hive was also maintained for comparing yield parameters.

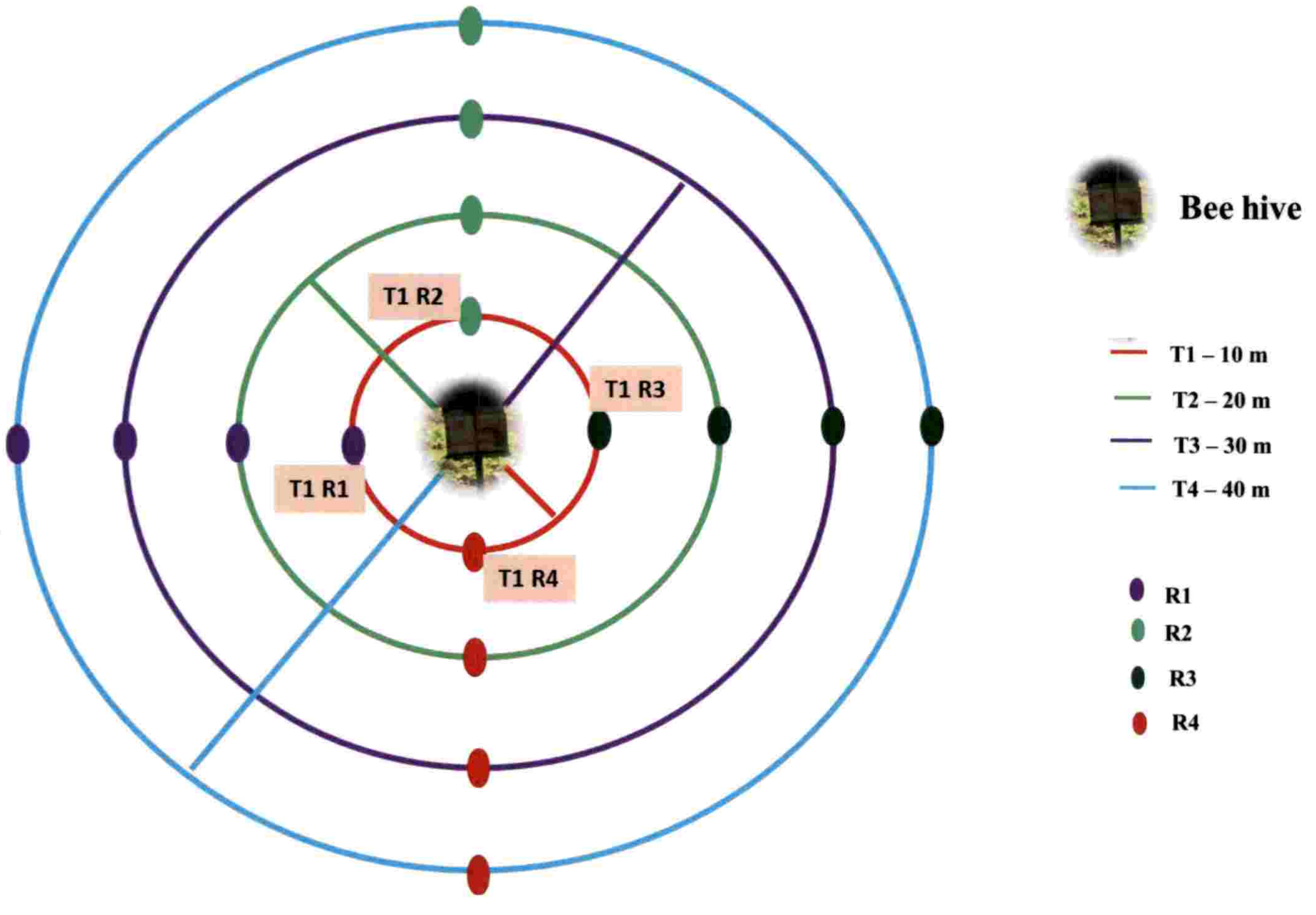


Figure 1. Lay out of the field

(A) General view of field

(B) Bee hive installed in the field

Plate 1. Field view of culinary melon

3.3.2. Foraging Intensity

Foraging intensity was recorded as detailed in 3.1.2.4. The observations were recorded at varying distances as well as time periods.

3.3.3 Observations on Yield Parameters of Culinary Melon

For standardising the number of bee hives required for optimum pollination in culinary melon, both qualitative and quantitative yield parameters *viz.,* number of female flowers, number of fruits, fruit length, fruit weight, number of deformed fruits, number of seeds per fruit and germination of seeds were recorded.

3.3.4 *Qualitative Parameters*

3.3.4.1 *Fruit Set*

Fruit set was determined by counting female flowers and number of fruits. Fully opened female flowers in four (replications) observational plants were tagged after ensuring bee visit. Tagged flowers which were developed into completely matured fruits were counted and expressed as per cent mean fruit set. Fruit set was obtained by the formula

$$\text{Fruit set} = \frac{\text{Total number of fruits per plant}}{\text{Total no. of female flowers per plant}} \times 100$$

3.3.4.2 *Deformed Fruits*

The tagged female flowers that developed into irregularly shaped fruits from each observational plant were counted as deformed fruits. It was expressed as follows

$$\text{Deformed fruits (\%)} = \frac{\text{Total number of deformed fruits per plant}}{\text{Total number of fruits per plant}} \times 100$$

3.3.4.3 *Fruit Length*

From each observational plant, four completely developed matured fruits were selected at random. The distance from stalk end to the apical curvature of the fruits were recorded and expressed as average fruit length.

3.3.5 *Quantitative Parameters*

3.3.5.1 *Fruit Weight*

Fruits were selected as per 3.3.4.3 for measuring single fruit weight. Weight of each fruit was measured and expressed as average single fruit weight.

3.3.5.2 *Number of Seeds per Fruit*

Four completely developed ripened fruits were selected at random from each observational plant. Seeds were separated from fruits. Total number of seeds per fruit was counted and expressed as average number of seeds per fruit.

3.3.5.3 *Germination Per Cent*

Fruits were selected as per 3.3.5.2 for assessing germination percentage of seeds. Seeds from these fruits were extracted, washed thoroughly and bulked to form seed lots for each treatment. Seeds were shade dried and then subjected to germination test. Wet paper method was used for studying germination per cent (Plate 2). Hundred seeds were selected from bulked seed lots for each treatment. Seeds were placed on moistened filter paper in petri plates. The germinated seeds were counted for five days. After five days, mean germination percentages for every treatment were worked out as follows

$$\text{Germination per cent} = \frac{\text{Number of germinated seeds}}{\text{Total number of seeds}} \times 100$$

u5

Plate 2. Germination study of seeds

3.3.6 Estimation of Number of *A. cerana* Colonies Required for Maximizing Yield

The radial distance at which the plants were performing well was taken as effective pollination range by *A. cerana*. The area of the circle, with this pollination range as the radius was calculated. Stock density (number of bee hives required for 1 ha) of *A. cerana* for culinary melon was determined by dividing one hectare area by this calculated area (Kumari, 2014).

Economic analysis using benefit cost ratio was done for assessing economic feasibility of each treatment. The treatment which was both economically and technically feasible was considered as effective treatment. Yield parameters of better treatment under augmented pollination were compared with control plot to assess the enhancement in yield due to augmented pollination.

$$\text{Stock density} = \frac{10{,}000\ \text{m}^2}{A}$$

A = Effective pollination area ($A = \pi r^2$),
r = Effective radial distance at which yield parameters are higher

3.3.7 Statistical Analysis

The collected data was analysed using Completely Randomised Design after subjecting to square root transformation wherever required. Enhancement in yield due to augmented pollination was analysed using independent t test.

Results

4. RESULTS

The study entitled 'Augmentation of pollination in culinary melon (*Cucumis melo* var. *acidulus*) with Indian bee (*A. c. indica*)' was conducted at farmers' field Kulathoor, Thiruvananthapuram and Department of Agricultural Entomology, College of Agriculture, Vellayani from 2017 to 2019 April. The results of the study are analysed and presented in this chapter.

4.1. INSECT POLLINATOR DIVERSITY AND FORAGING BEHAVIOUR OF DOMINANT POLLINATOR

Diverse insect fauna that visited the crop plant during study period are enlisted in Table 1. Among the seventeen insect species observed, there were pests, natural enemies and pollinators which belong to Hymenoptera, Lepidoptera, Coleoptera and Diptera.

4.1.1 Insect Pest

Total of four insect species belonging to Diptera (1), Coleoptera (2) and Lepidoptera (1) were recorded as pest of culinary melon (Table 1, Plate 3). Melon fly (*Bactrocera cucurbitae*, Tephritidae) was the major and only Dipteran pest observed in the field which caused damage to fruits. Main coleopteran pest encountered were pumpkin beetle (*Aulacophora foveicollis*) and leaf beetle (*Luperomorpha vittata*) which belonged to family chrysomelidae. Pumpkin beetle fed mainly leaves and flowers while leaf beetle fed on pollen grains. The only lepidopteran pest spotted was tobacco caterpillar (*Spodoptera litura*, Noctuidae) which was feeding on flowers.

4.1.2 Natural Enemies

Natural enemies were recorded only from the order Coleoptera (Table 1, Plate 4). Two species of coccinellid beetles *viz.*, *Cheilomenes sexmaculata* and *Coccinella transversalis* were the predators encountered in the field.

Table 1. Insect fauna on culinary melon (*C. melo* var. *acidulus*)

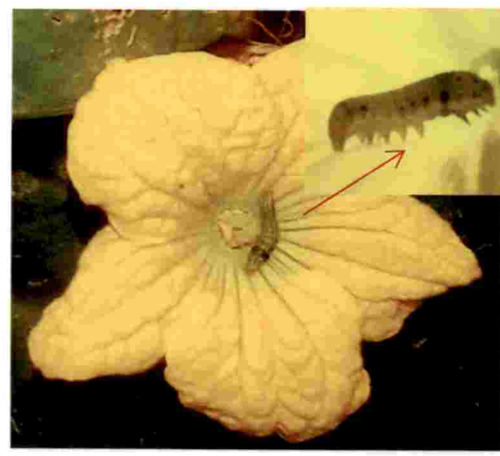
Sl. No.	Common name	Scientific name	Family	Order	Pest/ Pollinator/ *NE
1	Melon fly	*Bactrocera cucurbitae* (Coquillet)	Tephritidae	Diptera	Pest
2	Tobacco caterpillar	*Spodoptera litura* (Fabricius)	Noctuidae	Lepidoptera	Pest
3	Pumpkin beetle	*Aulacophora foveicollis* (Lucas)	Chrysomelidae	Coleoptera	Pest & Pollinator
4	Leaf beetle	*Luperomorpha vittata* (Duvivier)	Chrysomelidae	Coleoptera	Pest & Pollinator
5	Coccinellid beetle	*Coccinella transversalis* (Fabricius)	Coccinellidae	Coleoptera	NE
6	Coccinellid beetle	*Cheilomenes sexmaculata* (Fabricius)	Coccinellidae	Coleoptera	NE
7	Indian bee	*Apis cerana indica* (Fabricius)	Apidae	Hymenoptera	Pollinator
8	Small carpenter bee	*Ceratina hieroglyphica* (Smith)	Apidae	Hymenoptera	Pollinator
9	Small green carpenter bee	*C. binghami* (Cockrell)	Apidae	Hymenoptera	Pollinator
10	Small carpenter bee	*C. unimaculata* (Smith)	Apidae	Hymenoptera	Pollinator
11	Stingless bee	*Tetragonula travancorica* (Shanas & Faseeh)	Apidae	Hymenoptera	Pollinator
12	Braunaspis bee	Braunaspis sp.	Apidae	Hymenoptera	Pollinator
13	Blue banded bee	*Amegilla zonata* (Linnaeus)	Apidae	Hymenoptera	Pollinator
14	Blue butterfly	*Lampides boeticus* (Linnaeus)	Lycaenidae	Lepidoptera	Pollinator
15	Small cabbage white butterfly	*Leptosia nina* (Fabricius)	Pieridae	Lepidoptera	Pollinator
16	Unidentified		Pterophoridae	Lepidoptera	Pollinator
17	Ant	*Camponotus* sp.	Formicidae	Hymenoptera	Flower visitor

* Natural enemy

(A) Symptom of fruit fly attack
(*Bactrocera cucurbitae*)

(B) Pumpkin beetle
(*Aulacophora foevicollis*)

(C) Leaf beetle
(*Luperomorpha vittata*)



(D) Tobacco leaf caterpillar
(*Spodoptera litura*)

Plate 3. Insect pests on culinary melon

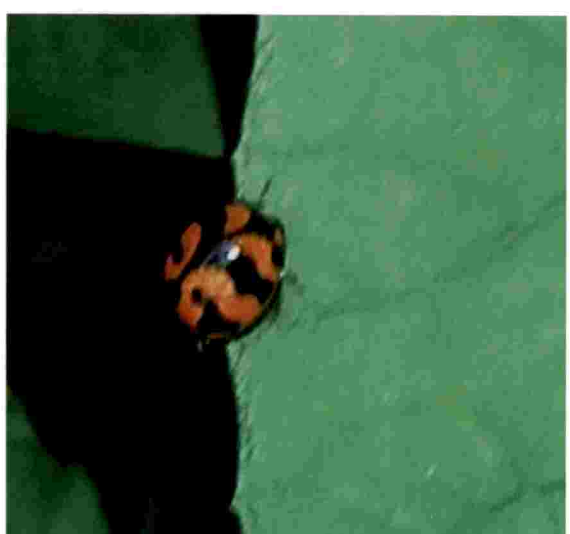


Plate 4. Coccinellid beetle (*Coccinella transversalis*)

(A) Indian bee
(*Apis cerana indica*)

(B) Small green carpenter bee
(*Ceratina binghami*)

(C) Braunaspis bee
(*Braunaspis* sp.)

(D) Small green carpenter bee
(*Ceratina binghami*)

(E) Stingless bee
(*Tetragonula travancorica*)

(F) Ants
(*Campotonotus* sp.)

Plate 5. Hymenopteran pollinators on culinary melon

(A) Blue butterfly
(*Lampides boeticus*)

(B) Small cabbage white butterfly
(*Leptosia nina*)

(C) Unidentified

Plate 6.Lepidopteran pollinators on culinary melon

(A) Pumpkin beetle
(*Aulacophora foevicollis*)

(B) Leaf beetle
(*Luperomorpha vittata*)

Plate 7. Coleopteran pollinators on culinary melon

4.1.3 Insect Pollinators or Flower visitors

Insect pollinators /flower visitors of culinary melon comprised of thirteen species which comes under Hymenoptera, Lepidoptera and Coleoptera. Majority of insect pollinators belong to Hymenoptera (7) followed by Lepidoptera (3) and Coleoptera (2). All Hymenopteran pollinators (Table 1, Plate 5) such as Indian bee (*A. c. indica*), small carpenter bee (*Ceratina hieroglyphica*), braunaspis bee (*Braunaspis* sp.), small green carpenter bee (*C. binghami*), small carpenter bee (*C. unimaculata*), stingless bee (*Tetragonula travancorica*) and blue banded bee (*Amegilla zonata*) belonged to family Apidae.

Lepidopteran pollinators (Table 1, Plate 6) observed were blue butterfly (*Lampides boeticus*, Lycaenidae) and small cabbage white butterfly (*Leptosia nina,* Pieridae). In addition an unidentified pollinator which belonged to family Pterophoridae was also present in the field. Pumpkin beetle (*A. foveicollis*) and leaf beetle (*L. vittata*) belonging to Chrysomelidae were the coleopteran pollinators (Table 1, Plate 7) encountered in the field. The only flower visitor recorded (*Camponotus* sp., Formicidae) was from the order Hymenoptera which occasionally visited flowers.

4.1.3.1 *Relative Abundance of Insect Pollinators Visiting Culinary Melon*

Relative abundance of major insect pollinators *viz., A. c. indica, C. hieroglyphica, Braunaspis* sp.*, C. binghami, T. travancorica, L. boeticus* and other pollinators (beetles, butterflies and ants) from 0600 h to 1800 h during peak flowering period are presented in Table 2.

A. c. indica was present in the field throughout the observation periods except for the time period of 0600 to 0700 h. The data presented in the table indicated that there exist significant variations in Indian bee population at different hours of the day. Significantly higher population (12.87 bees m^{-2} 5 $min.^{-1}$) was observed at the time period of 1000 to 1100 h. Significant decrease in population was observed during afternoon hours. The abundance of bees were

Table 2. Relative abundance of insect pollinators visiting culinary melon (*C. melo* var. *acidulus*)

Time period (h)	Number of insect pollinators visiting the plants m^{-2} 5 $min.^{-1}$						
	A. c. indica	*C. hieroglyphica*	*Braunaspis* sp.	*C. binghami*	*L. boeticus*	*T. travancorica*	Other insects
0600 – 0700	0.00 $(0.70)^{d}$	0.00 $(0.70)^{c}$	0.00 $(0.70)^{c}$	0.00 $(0.70)^{b}$	0.00 $(0.70)^{b}$	0.00 $(0.70)^{b}$	0.00 $(0.70)^{c}$
1000 – 1100	12.87 $(3.61)^{a}$	1.31 $(1.34)^{a}$	0.75 $(1.11)^{a}$	0.56 $(1.02)^{a}$	0.31 $(0.89)^{a}$	0.25 $(0.86)^{a}$	0.69 $(1.09)^{a}$
1400 – 1500	8.81 $(3.03)^{b}$	0.69 $(1.08)^{b}$	0.44 $(0.97)^{b}$	0.06 $(0.75)^{b}$	0.31 $(0.88)^{a}$	0.06 $(0.75)^{ab}$	0.69 $(1.09)^{a}$
1700 – 1800	0.75 $(1.11)^{c}$	0.00 $(0.70)^{c}$	0.00 $(0.07)^{c}$	0.00 $(0.70)^{b}$	0.00 $(0.07)^{b}$	0.00 $(0.70)^{b}$	0.25 $(0.86)^{b}$
CD (0.05)	(0.295)	(0.151)	(0.112)	(0.118)	(0.146)	(0.117)	(0.146)

*Mean of seven observations

Figures in parenthesis are $\sqrt{x + 1}$ transformed values recorded as 8.81 and 0.75 bees m^{-2} 5 $min.^{-1}$, during 1400-1500 h and 1700 h -1800 h respectively, latter being the least population.

C. hieroglyphica recorded its peak abundance (1.31 m^{-2} 5 $min.^{-1}$) during the time period of 1000 to 1100 h. Significantly lower population (0.69 bees m^{-2} 5 $min.^{-1}$) was observed between 1400 to 1500 h of the day. No bees could be encountered in the field either in morning (0600 to 0700 h) or evening (1700 to 1800 h) observation periods.

Maximum number of *Braunaspis* sp. was recorded during 1000 to 1100 h (0.75 bees m^{-2} 5 $min.^{-1}$) which was followed by the bee population (0.44 bees m^{-2} 5 $min.^{-1}$) during 1400 to 1500 h. No bees were recorded in the field either in morning (0600 to 0700h) or evening (1700 to 1800 h) observation periods.

C. binghami recorded maximum population (0.56 bees m^{-2} 5 $min.^{-1}$) during the time period of 1000 to 1100 h. This was followed by time periods 0600 to 0700 h, 1400 to1500 h and 1700 to 1800 h which were statistically on par. The mean population found during 1400 to 1500 h was 0.06 bees m^{-2} 5 $min.^{-1}$ whereas none of bees were recorded between 0600 to 0700 h and 1700 to 1800 h.

Maximum population of Lepidopteran pollinator was recorded both during forenoon and afternoon. The mean population of *L. boeticus* during 1000 to 1100 h and 1400 to 1500 h were uniform and was recorded as 0.31 butterflies m^{-2} 5 min^{-1}. No butterflies were observed visiting the flowers during the time periods of 0600 to 0700 h and 1700 to 1800 h.

T. travancorica recorded peak population during 1000 to 1100 h (0.25 bees m^{-2} 5 $min.^{-1}$) which was on par with population during 1400 to 1500 h (0.06 bees m^{-2} 5 $min.^{-1}$). There was no significant difference in population during 1400 to 1500 h, 1700 to 1800 h and 0600 to 0700 h. No bees were observed in the field during 0600 to 0700 h.

The peak populations (0.69 insects m^{-2} 5 $min.^{-1}$) of other pollinators like beetles, butterflies and ants were recorded both during 1000 to 1100 h and 1400 to

1500 h which were on par. Lower populations (0.25 insects m^{-2} 5 $min.^{-1}$) were observed between 1700 to 1800 h. Neither beetles, butterflies, nor ants visited the flowers during 0600 to 0700 h.

The results on relative abundance revealed that maximum number of pollinators was recorded during 1000 -1100 h. Among the pollinators, *A. c. indica* was found to be superior to other pollinators in terms of relative abundance (12.87 bees m^{-2} 5 $min.^{-1}$).

4.1.3.2 *Foraging Behaviour of A. c. indica*

Foraging behaviour of dominant pollinator, *A. c. indica* at different time periods (0600-0700 h, 1000-1100 h, 1400-1500 h and 1700-1800 h) is detailed in Table 3. To study the foraging behaviour, initiation and cessation of foraging activity, no. of flowers visited $min.^{-1}$ (foraging rate), time spent by bees per flower (foraging speed), no. of bees visiting blooms m^{-2} $min.^{-1}$ (foraging intensity), mode of alighting of individuals (foraging mode) and proportion of pollen and nectar gatherers were observed at different hours of the day during peak flowering period.

Observations on foraging time indicated that honey bees commenced foraging on 0700 h and ceased activity on 1800 h, thus rendering eleven hours of foraging time.

Foraging rate of honey bees at different time periods showed significant variations. Maximum numbers of flowers were visited during 1000 to 1100 h (14.17 flowers $min.^{-1}$). Thereafter decrease in foraging rates were observed. At the time period of 1400 to 1500 h foraging rate was recorded as 10.75 flowers $min.^{-1}$ which was followed by 8.40 flowers $min.^{-1}$ during 1700 to 1800 h. It was found that no bees were foraging on flowers of culinary melon during 0600 to 0700 h.

Foraging speed of honey bees was found to be lower during morning than afternoon hours. Significant difference in time spent on male and female flowers was observed. Least time was spent by bees on flowers was during 1000 to 1100 h

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Table 3. Foraging behaviour of dominant pollinator *A. c. indica*

Time period (h)	*No. of flowers visited min^{-1}	*Time spent (sec.)		No. of bees visiting blooms m^2 $min.^{-1}$	* Foraging mode	Proportion of N and P
		Male flower	Female flower			
0600 – 0700	0 (0.07)^d	0 (0.07)^c	0 (0.07)^c	0 (0.70)^c	No bee activity	No bee activity
1000 - 1100	14.17 (3.84)^a	2.37 (1.69)^b	12.70 (3.62)^b	1.60 (1.45)^a	All top workers	**N
1400 - 1500	10.75 (3.36)^b	3.85 (2.09)^a	14.70 (3.89)^a	0.82 (1.15)^b	All top workers	N
1700 - 1800	8.40 (2.98)^c	3.78 (2.12)^a	15.00 (3.93)^a	0.05 (0.73)^c	All top workers	N
CD (0.05)	(0.050)	(0.074)	(0.131)	(0.179)		

*Mean of 10 observations

**N-Nectar gatherer, P-Pollen collector

Figures in parenthesis are $\sqrt{x + 1}$ transformed value

(2.37 sec. on male flower and 12.70 sec. on female flower). Maximum time spent on flowers was during 1400 to 1500 h (3.85 sec. on male flower and 14.70 sec. on female flower) and 1700 to 1800 h (3.78 sec. on male flower and 15.00 sec. on female flower) which were statistically on par. No bees were observed on flowers at the time period of 0600 to 0700 h.

During 1000 to 1100 h foraging intensity was recorded as 1.60 bees m^{-2} $min.^{-1}$ which was superior to all other time periods. Thereafter decrease in number of bees visiting blooms was recorded. During 1400 to 1500 h foraging intensity was recorded as 0.82 bees m^{-2} $min.^{-1}$ which was followed by time period 1700 to 1800 h (0.05 bees m^{-2} $min.^{-1}$). No bees were found visiting blooms between 0600 to 0700 h.

It was observed that all bees were alighting directly on top of stamen and hence were regarded as top workers. At all time periods none of the bees alighted at the base of stamen (side workers). Proportion of nectar gatherers and pollen gatherers were found to be non-significant during all time periods of the day. At the time period of 0600 to 0700 h no bees were foraging for nectar or pollen. Afterwards, bees foraged for nectar rather than for pollen.

4.1.3.3 *Influence of Weather Parameters on Foraging Behaviour*

The data on Table 4 shows correlation between temperature and foraging activity at varying time periods. Temperature showed significant positive correlation with foraging activity. As the temperature increases foraging activity was also found to be increasing. The rise in mean temperature from 36.06^{0}C to 36.75^{0}C resulted in an increase of foraging speed from 2.26 sec. to 3.78 sec. The correlation coefficient was obtained as 0.69.

The correlation between relative humidity and foraging activity at varying time periods is elucidated in Table 4. Foraging activity showed significant negative relation to relative humidity. Foraging activity of bees was found to be decreasing with increase in relative humidity. As mean relative humidity declined

Table 4. Influence of weather parameters on foraging activity of *A. c. indica*

Time period (h)	*Temp.(^{0}C)	*Foraging speed (sec.)	**RH (%)
0600 – 0700	28.58	0	73.93
1000 – 1100	36.06	2.26	53.71
1400 – 1500	36.85	3.64	54.00
1700 – 1800	36.75	3.78	51.07
r	0.69		- 0.57
r(0.05)	0.55		

*Mean of seven observations ** Relative humidity from 53.71 per cent to 51.07 per cent, foraging speed increased from 2.26 sec. to 3.78 sec. The correlation coefficient was obtained as – 0.57.

4.2. FLORAL BIOLOGY OF *C. melo* var. *acidulus*

In culinary melon, plant is monoecious and flowering started 24 days after sowing. The flowers were yellow with calyx and corolla having five sepals and petals each (Plate 8). Stamens were three and syngenesious (anthers united and filaments free). The pistillate flowers had three stigmatic lobes and an inferior ovary resembling fruits at the base. Floral nectaries were located inside at the base of stamen and stigma in staminate and pistillate flowers respectively (Plate 9). The nectaries were button-shaped mound at the centre in staminate flowers whereas nectary was flattened and formed continuous ring surrounding base of style in pistillate flowers. Anthesis was between 0700 to 0800 h during which staminate flowers opened initially followed by pistillate flowers. Male flowers remained opened for five days while female flowers opened for four days. Female flowers were receptive only on the day of flower opening and were non receptive for remaining days.

Observations on the parameters of floral biology of culinary melon *viz.*, flower spread, stamen length, basal gap between stamens, pistil length and proboscis length of bees were recorded to assess relationship between plant and pollinator. The data are presented in Table 5.

Size of male flowers ranged from 3.20 to 3.70 cm with a mean floral size of 3.45 cm. Standard deviation and coefficient of variation were found to be 0.14 cm and 4.06 respectively. Female flowers were larger and ranged from 3.70 to 4.20 cm with mean and standard deviation as 3.90 cm and 0.15 cm respectively. Coefficient of variation for female flowers was 3.85.

Maximum and minimum length of stamen was observed as 0.49 and 0.42 cm respectively with mean stamen length as 0.45 cm (Plate 9). Standard deviation was calculated as 0.03 cm while coefficient of variation was 6.66. Basal gap between stamens was recorded as 0.16 cm which was maximum while lowest

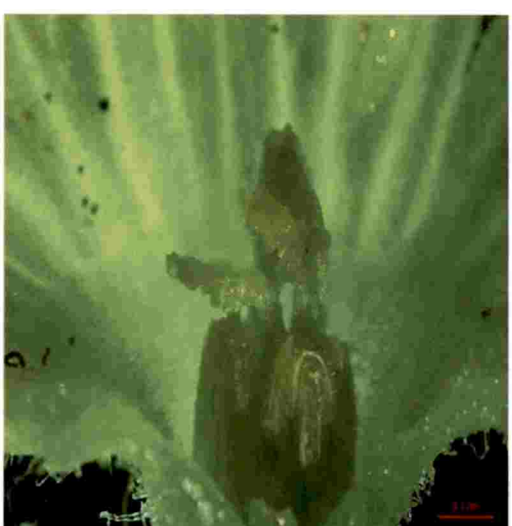
Table 5. Floral biology of culinary melon and proboscis length of bees

Sl. No.	Parameter	Flower spread		Stamen length	**BG between stamens	Pistil length	Proboscis length
		Male flower	Female flower				
1.	Maximum value (cm)	3.70	4.20	0.49	0.16	3.00	0.50
2.	Minimum value (cm)	3.20	3.70	0.42	0.14	2.40	0.48
3.	SD (cm)	0.14	0.15	0.03	0.01	0.20	0.01
4.	* Mean (cm)	3.45	3.90	0.45	0.15	2.65	0.49
5.	CV	4.06	3.85	6.66	6.66	7.55	2.04

* Mean of ten observations ** Basal gap

(A) Staminate flower

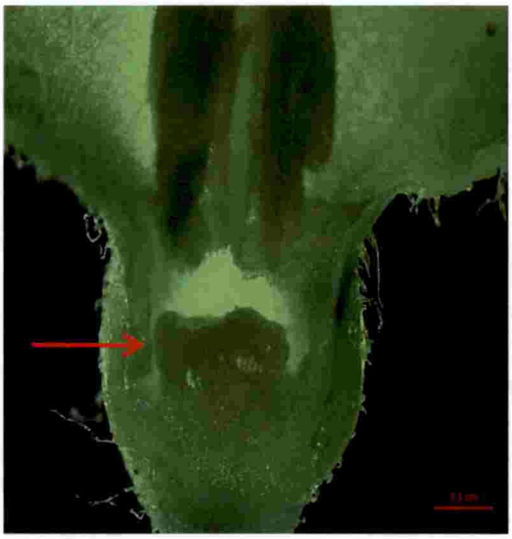
(B) Pistillate flower



(C) Stamen

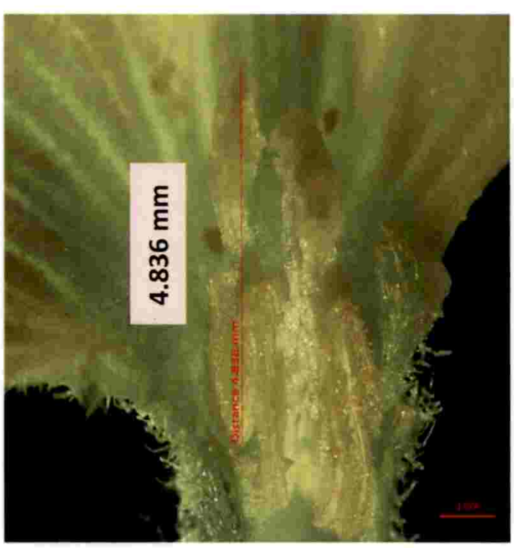
(D) Stigma

Plate 8. Staminate and pistillate flowers of culinary melon

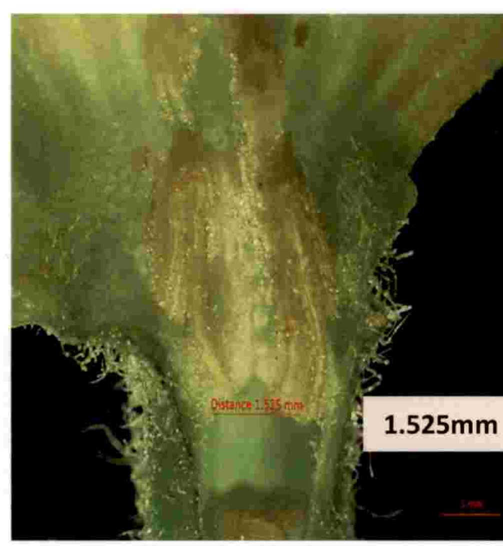


(A) Nectary of male flower

(B) Nectary of female flower



(C) Stamen length



(D) Basal gap between stamens

Plate 9.Floral biology of culinary melon (*C. melo* var. *acidulus*)

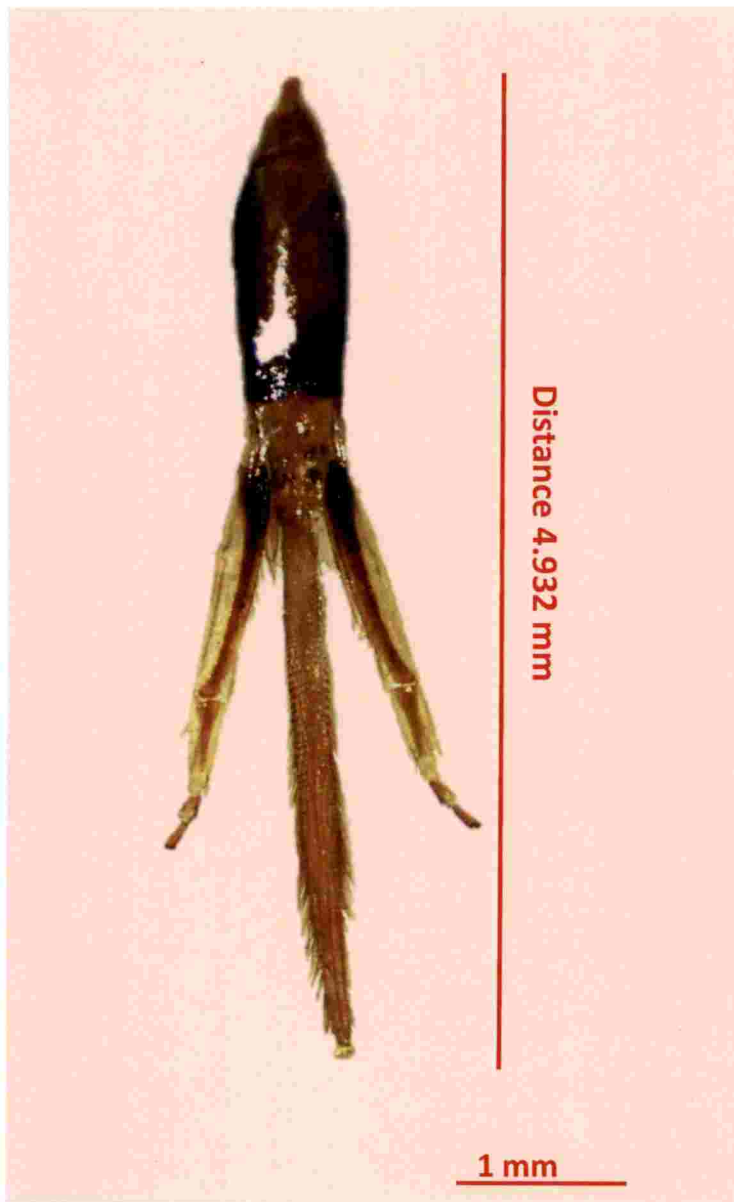


Plate 10. Proboscis length of Indian bee

distance between stamens was found to be 0.14 cm (Plate 9). Mean basal gap between stamens was recorded as 0.15 cm. standard deviation and coefficient of variation were 0.01cm and 6.66 respectively.

Length of pistil ranged from 2.40 to 3.00 cm, the mean value being 2.65 cm. Standard deviation and coefficient of variation were observed as 0.20 cm and 7.55 respectively.

Proboscis length of bees varied from 0.48 to 0.50 cm (Plate 10). Mean length of proboscis was 0.49 cm. Standard deviation and coefficient of variation was found to be 0.01 cm and 2.04 respectively.

4.3. STANDARDISATION OF BEE HIVES (*A. c. indica*)

Number of bee hives required for adequate pollination in culinary melon was estimated by observing the foraging intensity (number of bees m^{-2} $min.^{-1}$) as well as yield parameters.

4.3.1 *Foraging Intensity of A. c. indica*

The foraging intensity of Indian bees at varying distance (10, 20, 30 and 40 m) and time periods (0600-0700 h, 1000-1100 h, 1400-1500 h and 1700-1800 h) of the day is elucidated in Table 6.

During 1000 to 1100 h foraging intensity was recorded as 2.44 bees m^{-2} $min.^{-1}$ at 10 m distance which was superior to all other treatments irrespective of different time periods. There was no significant variation between number of bees visiting blooms at 20, 30 and 40 m distance, foraging intensities being 1.48, 1.35 and 1.14 bees m^{-2} $min.^{-1}$ respectively.

Decrease in foraging intensity was observed during afternoon hours. At the time period of 1400 to 1500 h, foraging intensity at 10 m distance was recorded as 1.2 bees m^{-2} $min.^{-1}$ which was highest. This was followed by 0.80, 0.74 and 0.56 bees m^{-2} $min.^{-1}$ at 20, 30 and 40 m respectively which were on par.

Table 6. Foraging intensity of *A. c. indica* with varying distance

Distance (m)	Time period (h)			
	0600 - 0700	1000 - 1100	1400 - 1500	1700 - 1800
	*Number of bees visiting blooms m^{-2} $min.^{-1}$			
10	0 (0.70)	2.44 (1.56)^{a}	1.20 (1.09)^{a}	0.13 (0.79)^{a}
20	0 (0.70)	1.48 (1.22)^{b}	0.80 (0.90)^{b}	0.06 (0.74)^{b}
30	0 (0.70)	1.35 (1.15)^{b}	0.74 (0.85)^{b}	0 (0.70)^{b}
40	0 (0.70)	1.14 (1.07)^{b}	0.56 (0.74)^{b}	0 (0.70)^{b}
CD (0.05)	NS	(0.180)	(0.163)	(0.044)

* Mean of four observations

Figures in parenthesis are $\sqrt{x} + 1$ transformed values

Similar trend was also observed during 1700 to 1800 h. Significantly higher number of bees (0.13 bees m^{-2} $min.^{-1}$) was recorded at 10 m distance. Foraging intensities at 20, 30 and 40 m distance showed no significant variation. Number of bees at 20 m was recorded as 0.06 bees m^{-2} $min.^{-1}$ while no bees were present at 30 and 40 m.

Honey bees were not foraging between 0600 to 0700 h as evidenced in the table. At all time periods significantly higher number of bees visited flowers at 10 m distance from the bee hive.

4.3.2 *Yield Parameters of Culinary Melon at Different Distance*

4.3.2.1 *Qualitative Parameters*

Qualitative parameters of culinary melon *viz.*, number of female flowers, number of fruits, number of deformed fruits and fruit length are detailed in Table 7.

No significant variation was observed in the number of female flowers per plant at different distances and it ranged from 12.06 to 12.31. The per cent fruit set showed significant variation with distance. Maximum fruit set was observed at 10 m distance (75.44 %) which was significantly highest from remaining distance. Fruit set at 20 and 30 m were on par and were recorded as 67.84 per cent and 66.62 per cent respectively. Least fruit set was recorded at 40 m distance (59.06 %).

Percentage deformed fruits varied significantly where the number of deformed fruits was found to be increasing with distance. Percentage deformed fruits (25.07 %) was recorded as least at 10 m distance while plants at 40 m recorded highest percentage (51.68 %). Plants at 20 and 30 m distance recorded 35.26 per cent and 39.00 per cent deformed fruits respectively.

Length of fruits also varied significantly at different distances with the maximum length at 10 m distance (26.22 cm).This was followed by fruit length at 20, 30 and 40 m distance which was recorded as 23.71, 22.09 and 20.16 cm respectively.

Table 7. Qualitative parameters of culinary melon (*C. melo* var. *acidulus)*

Distance (m)	*No. of female flowers	*Fruit set (%)	*Deformed fruits (%)	*Fruit length (cm)
10	12.12	75.44 [a]	25.07 [d]	26.22 [a]
20	12.06	67.84 [b]	35.26 [c]	23.71 [b]
30	12.31	66.62 [b]	39.00 [b]	22.09 [c]
40	12.31	59.06 [c]	51.68 [a]	20.16 [d]
CD (0.05)	NS	3.026	1.747	1.091

*Mean of four observations Figures in parenthesis are $\sqrt{x+1}$ transformed values

4.3.2.2 *Quantitative Parameters*

Quantitative parameters of culinary melon *viz.*, single fruit weight, number of seeds per fruit and germination per cent are presented in Table 8.

A similar trend to that of fruit set was observed in single fruit weight where plants at 10 m distance recorded maximum mean weight of 0.75 kg. No significant difference in fruit weight was observed at 20 and 30 m which recorded 0.55 kg fruit weight. Least fruit weight (0.47 kg) was recorded at 40 m.

Number of seeds per fruit was recorded maximum at 10 m distance (847.50) which was followed by plants at 20 m distance (764.50). Plants at 30 and 40 m were found to be on par which recorded 714.75 and 629.50 seeds per fruit respectively.

Germination per cent showed significant difference with varying distance. Highest germination was recorded at 10 m distance (90.50 %) followed by 20 and 30 m distance with 84.25 per cent and 80.25 per cent respectively. Least germination per cent was observed at 40 m distance (68.75 %).

4.3.3 *Estimation of Number of Bee Hives (A. c. indica)*

The radial distance at which plants exhibited better performance in terms of yield parameters was assessed and used for further evaluations. Number of bee hives required for one ha at varying pollination ranges and benefit cost ratio including these stock densities are detailed in Table 9.

Thus by analysing the yield parameters, plants at 10, 20 and 30 m distances were found to be performing better than that of plants at 40 m distance. Hence the number of bee hives required for adequate pollination in culinary melon was worked out with these effective distances as radius of optimally pollinated area by *A. cerana*. Accordingly, stock density was calculated as 31.80, 7.90 and 3.50 for 10, 20 and 30 m pollination ranges respectively. Longest pollination range 40 m resulted in a stock density of 1.9.

Table 8. Quantitative parameters of culinary melon (*C. melo* var. *acidulus)*

Distance (m)	*Single fruit weight (kg)	*No. of seeds per fruit	*Germination per cent
10	0.75 [a]	847.50 (29.11) [a]	90.50 (9.52) [a]
20	0.55 [b]	764.50 (27.64) [b]	84.25 (9.18) [b]
30	0.55 [b]	714.75 (27.73) [c]	80.25 (8.96) [c]
40	0.47 [c]	629.50 (26.31) [c]	68.75 (8.44) [d]
CD (0.05)	0.017	(0.602)	(0.219)

*Mean of four observations   Figures in parenthesis are $\sqrt{x} + 1$ transformed values

Table 9. Stock density and B:C at varying pollination range

Sl. No.	Pollination range (m)	Stock density	B:C
1	10	31.80	2.7
2	20	7.90	2.4
3	30	3.50	2.5
4	40	1.90	1.9

Benefit cost ratio at different distance in augmented pollination was calculated (Appendix I), where maximum B:C was obtained at 10 m (2.7) followed by 30 m (2.5). Considering the economic as well as technical feasibility, pollination range of 30 m was selected as effective distance. Thus it was found that 3.5 ~ 4 nos. of Indian bee colonies with six bee frame strength is adequate for an effective pollination in one hectare of culinary melon.

4.3.4 *Comparison of Yield Parameters under Augmented and Control Plots*

Yield parameters of culinary melon *viz.*, fruit set, deformed fruits, fruit length, fruit weight, number of seeds per fruit and germination per cent both in augmented and control plots are given in Table 10.

The data in the table indicated that performance of culinary melon was better in augmented plots than in control plots. All of the yield parameters were significantly higher ($p < 0.05$) in augmented plots compared to control plots. Fruit set was recorded as 66.62 per cent in augmented plots against 57.17 per cent in control plots. Percentage deformed fruits were lower in augmented plots (39.00 %) while control plots recorded high percentage of deformed fruits (54.91 %). The augmented pollination resulted in good quality, larger and longer fruits (0.55 kg, 22.09 cm) whereas poor quality fruits of lower weight and shorter length (0.42 kg, 19.56 cm) were obtained from control plots (Plate 11). Seed quality was also enhanced by augmented pollination as evidenced from higher number of seeds and germination (714.75 nos., 80.25 %) against least number of seeds and germination (589.25 nos., 68.75 %) in control plots. Improved quality and quantity of fruits ultimately resulted in 57.50 per cent enhanced yield in augmented plots over the control plants.

Table 10. Comparison of yield parameters under augmented and control plot

Sl. No.	Yield parameters	Augmented plot (Optimum pollination range - 30 m)	Control plot	t - value
1	Fruit set (%)	66.62	57.17	4.345
2	Deformed fruits (%)	39	54.91	6.992
3	Fruit length (cm)	22.09	19.56	5.434
4	Fruit weight (kg)	0.55	0.41	10.386
5	No. of seeds per fruit	714.75	589.25	
6	Germination per cent	80.25	68.75	
7	t – value	2.101		

(A) Augmented plot

(B) Control plot

Plate 11. Fruits from augmented and control plots

Discussion

5. DISCUSSION

The present investigation on 'Augmentation of pollination in culinary melon with Indian bee' was carried out at farmers' field Thiruvananthapuram and Department of Agricultural Entomology, College of Agriculture, Vellayani to study the foraging behaviour and to standardise bee hives for yield enhancement in culinary melon. The results of the study are discussed below:

Beekeeping for yield enhancement is being practiced by farmers for centuries world over. Mc Gregor (1976) has claimed beekeeping as an input which is comparable to the other inputs of crop production, such as seeds, pesticides and fertilizers. Bee pollination is considered as one of the effective and cheapest input for triggering the crop yield both qualitatively and quantitatively. The enhancement in yield due to bee pollination in various crops has been recorded as 5 to 33150 per cent (National Bee Board, 2017). Planned bee pollination has now become a strategy for maximizing production.

Researches in planned bee pollination have been carried out throughout the world for yield enhancement. Endeavours have been there to determine the number of honey bee colonies required for increased yield. Accordingly bee hives required for adequate pollination in cucurbits have been estimated. Though stock density of *A. mellifera* for planned bee pollination in *Cucumis melo* is available, the recommendations may vary from place to place based on efficiency of bee species (Abrol, 2007). However researches on requirement of *A. cerana* colonies, the most commonly managed bee species in India for yield enhancement of *C. melo* are scanty. Hence there is a need to assess the number of colonies required for adequate pollination in culinary melon.

The present study focussed on pollinator diversity in culinary melon from which dominant pollinator was assessed and its foraging behaviour was also studied. Finally, the number of bee hives required for optimum pollination and increased yield was estimated.

5.1. INSECT POLLINATOR DIVERSITY AND FORAGING BEHAVIOUR OF DOMINANT POLLINATOR

Being an entomophilus crop, cucurbits have always attracted number of insects including pests, natural enemies and pollinators (Figure 2). Adaptive morphological characters of flowers which make them fit to insect pollinators are showy corolla, large amount of high grade nectar and heavy and sticky pollen grains (Fronk and Slater, 1956). Many have reported diversity of insects and pollinators on cucurbit agroecosystem (Balachandran *et al.,* 2017).

In the current investigation a total of seventeen insect species were observed in culinary melon. *B. cucurbitae, A. foevicollis, L. vittata* and *S. litura* were observed as pest of culinary melon. *C. transversalis* and *C. sexmaculata* were the predators observed. The same has been recorded by scientists (Kaur *et al.,* 2010; Sunil *et al.*, 2017).

Pollinators belonging to Hymenoptera, Lepidoptera and Coleoptera were recorded in the current study. Hymenopteran insects contributed to majority (58.33 %) of insect fauna (Figure 3) followed by Lepidopteran (25.00 %) and Coleopteran (16.66 %). Fifteen different insect pollinators were recorded in culinary melon by Boli (2013) wherein Hymenopterans were dominant (40.00 %) followed by Coleoptera (20.00 %), Lepidoptera (16.00 %), Diptera (16.00 %) and Hemiptera (8.00 %).

The honey bees, butterflies and beetles were reported as common pollinators of cucurbits. Shrivastava (1991) have described the mechanisms by which insect species aid in pollination. While alighting on flowers pollen loaded notum of bees touches stigma which facilitate pollen transfer (Cephalotribic mode). Butterflies transfer pollen through proboscis during their probe for nectar. The proboscis passes over stigmatic surface by just touching the extrorse papillate surface which result in pollen transfer by siphonotribic mode. In case of beetles, pollen gets dusted mainly on sternum and will be transferred to stigma during their visit to female flowers (Sternotribic mode).

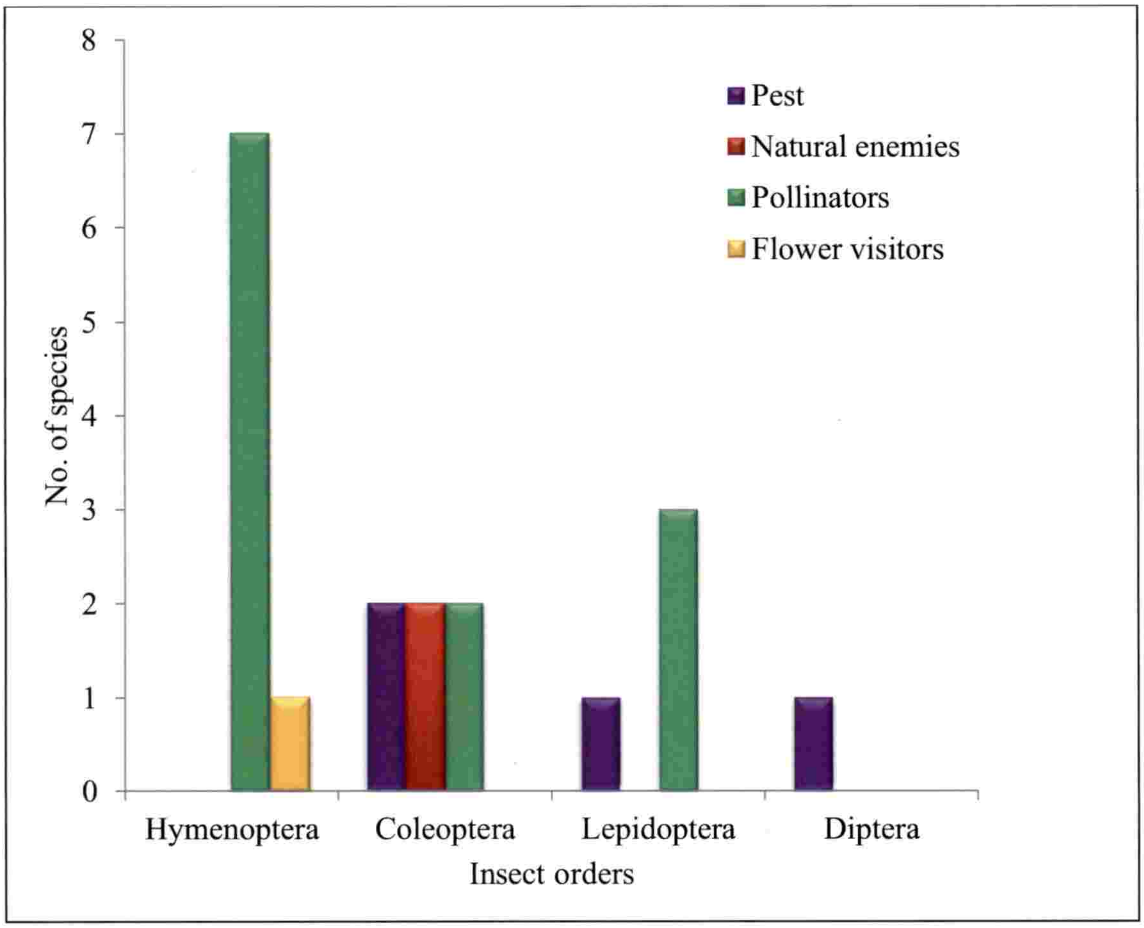


Figure 2. Insect fauna on culinary melon (*C. melo* var. *acidulus*)

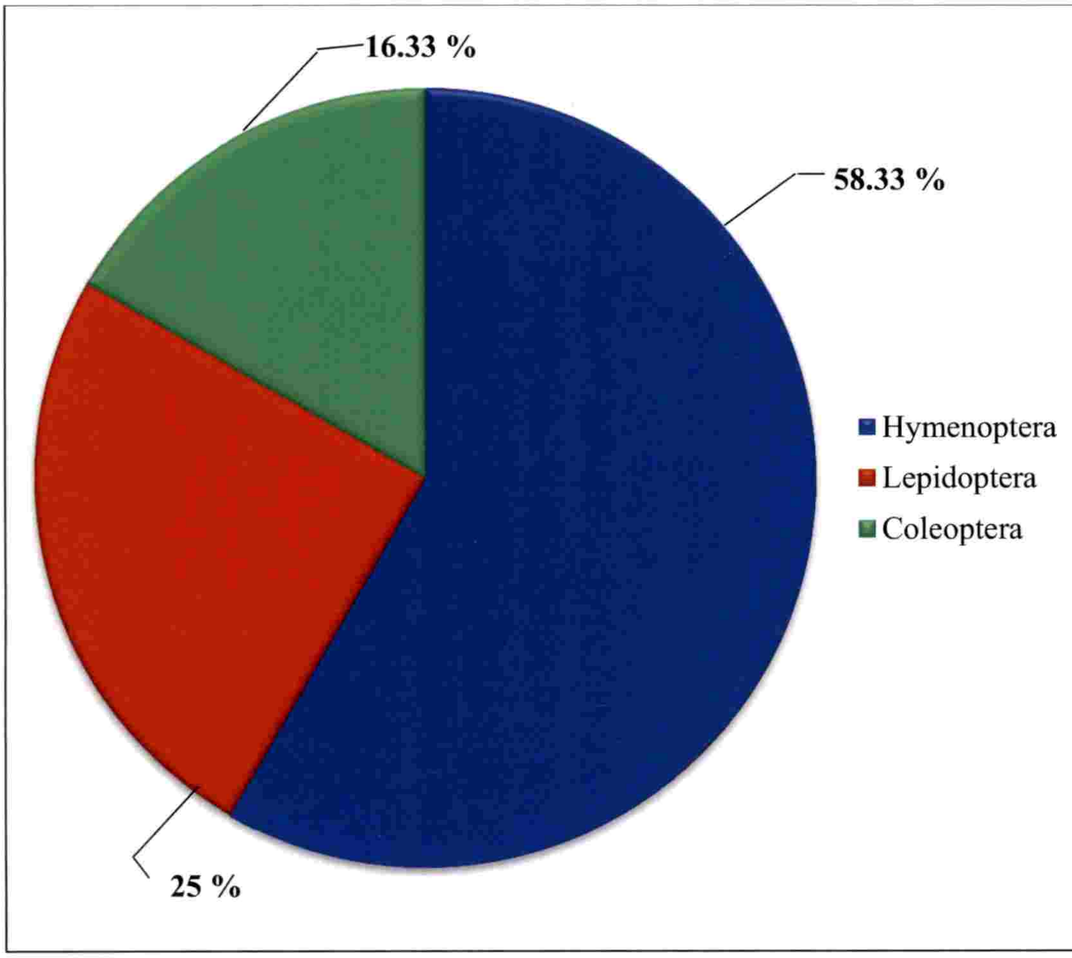


Figure 3. Pollinator diversity in culinary melon (*C. melo* var. *acidulus*)

Ants were the only flower visitors observed in the field which occasionally visited flowers and rarely made contact with stamens. Kevan and Baker (1983) claimed that Formicidae are generally frequent flower visitors, since they must walk through vegetation as they go from plant to plant which in turn reduces efficiency of pollination.

Upon analysing data on pollinator abundance, *A. c. indica* was assessed as dominant pollinator with a relative abundance of 12.87 bees m^{-2} 5 $min.^{-1}$ which was followed by *C. hieroglyphica* (1.31 bees m^{-2} 5 $min.^{-1}$) during 1000-1100 h (Figure 4). Maximum number of pollinators was recorded during 1000 -1100 h. Afterwards, pollinator population showed a decline with advance of time. On the other hand no pollinators were observed in the field during the time period 0600-0700 h. The results are in agreement with that of Satheesha (2010) wherein peak population of *A. cerana* in cucumber flowers was 11.20 bees m^{-2} 5 $min.^{-1}$ during 1000 to 1100 h. All pollinators recorded their peak abundance during 1000 to 1100 h. Highest population of *A. cerana* on culinary melon was recorded as 7.67 bees m^{-2} 5 $min.^{-1}$ during 1000 to 1200 h by Raeesa (2018). This was significantly higher than all other time periods.

The abundance of pollinators during 1000 to 1100 h and difference in diurnal activity of pollinators with varying time periods observed in the present study can be attributed to time of anthesis and available floral rewards of crop. According to Cervancia and Bergonia (1991) nectar secretion in cucurbits peaked from three to four hours after anthesis which coincides with time period 1000-1100 h. Consequently abundance of pollinators will be maximum during these time periods.

The pollinator population was least during 1700 to 1800 h. As time advances depletion of floral resources occurs and such resources are least preferred by insects (Collison and Martin, 1979). No pollinators foraged on cucumber flowers during 0600 to 0700 h which is attributed to time of anthesis.

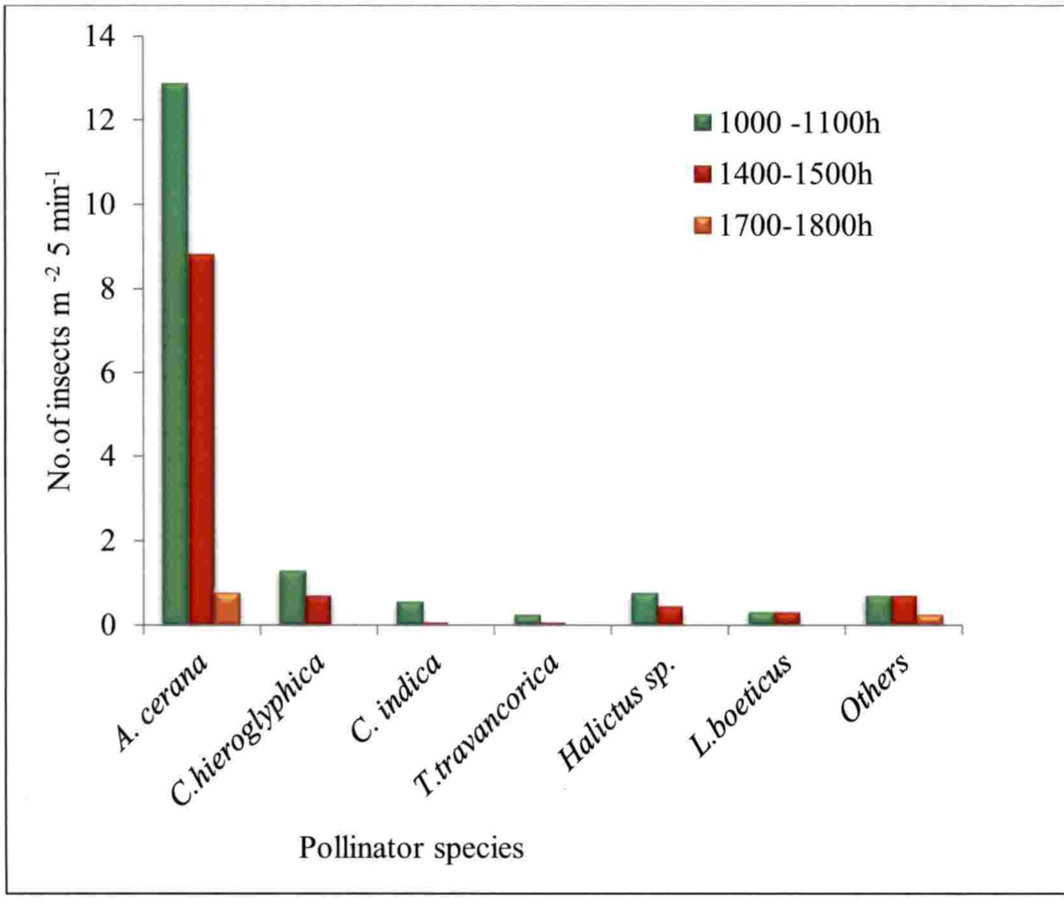


Figure 4. Relative abundance of pollinator species in culinary melon (*C. melo* var. *acidulus*)

In culinary melon flower opening was observed on 0700 h. Similar results were observed in cucumber in which anthesis was at 07.30 h (Rubina, 2010).

Honey bees commenced foraging on culinary melon by 0700 h and ceased activity by 1800 h. Thus they rendered eleven hours of foraging time on culinary melon. The present study showed slight deviation from the observations of Rani *et al.* (2017). In Hariyana *A. cerana* commenced foraging on *Cucurbita pepo* at 0700 h and ceased activity at 1700 h. The deviation can be due to difference in prevailing weather conditions of experimental sites.

Foraging mode of bees was observed as top workers. These findings are in conformity with Premila *et al.* (2014), all the *A. cerana* foragers being top workers in culinary melon. All bees were observed as foraging for nectar irrespective of time periods in the present study. Nectar foragers are efficient in monoecious cucurbits, as only they are capable of pollen transfer from staminate to pistillate flowers, which results in pollination (Bomfim *et al.,* 2016).

Generally flight activity of bees decreased with progress of time. Foraging rate as well as foraging intensity of bees was found to be decreasing with advance of time and peak was recorded during 1000 to 1100 h (Figure 5). The foraging rate was 14.17 flowers min.$^{-1}$ and foraging intensity was 1.63 bees m^{-2} min.$^{-1}$. The maximum foraging rate and foraging intensity of *A. cerana* on culinary melon blooms was recorded as 4.77 flowers min.$^{-1}$ (Premila *et al.*, 2014) and 2.80 bees m^{-2} min.$^{-1}$ (Raeesa, 2018) in Kerala.

The peak activity of pollinators during 1000 to 1100 h is due to peak nectar secretion in cucurbits after three to four hours of anthesis as explained by Cervanica and Begonia (1991). Further reduction in activity is due to interplay between availability of floral reward (nectar and pollen) with weather conditions which is explained by Reddy *et al.* (2015). As time advances, temperature increases, depletion of floral rewards occurs which subsequently lead to decreased rate of foraging during late hours. In addition, elevated temperature necessitates more number of bees to regulate colony temperature which should be maintained constant around 32^{0}C for proper development. Honey bee larvae and pupae being extremely stenothermic (strong dependence on accurate regulation of brood nest temperature) require this thermoregulation which in turn needs more bees. Thus the number bees foraging on blooms reduce in late hours.

Unlike foraging rate and intensity, foraging speed increased with advance of time. The average time spent increased from 2.37 to 3.85 sec. on male flowers and 12.70 to 15.00 sec. on female flowers with progress of time. This fluctuation is due to availability of nectar which is explained by Collison *et al*. (1979). As bee density increased after 0900 h the visits became shorter, because the flowers had only partially replenished their nectar supply, depleted by earlier bee visits. During afternoon hours foraging population decreases which allowed a greater accumulation of nectar, resulting in longer visits. Reddy *et al*. (2015) claimed another reason for prolonged visits in afternoon hours. Increasing temperature results in solidification of available nectar and harvest of such solidified nectar require more time and energy. Consequently bees spent more time in afternoon hours.

In the present study, significant difference in time spent on male and female flowers was observed (Figure 6). The bees spent longer time on female flowers compared to male flowers at all observational time periods. Similar observations were recorded by Collison *et al*. (1979) in cucumber (*Cucumis sativus*) in USA. The average duration of a visit fluctuated throughout the day between 3.4 and 12.8 sec. for staminate flowers and between 6.1 and 19.7 sec for pistillate flowers. The pistillate flowers produced 1.7 times as much nectar as staminate flowers, which resulted in longer duration of visit on female flowers. Increased nectar volume in female flowers (*C. pepo*) is attributed to large secretary surface and greater density of stomata (Nepi *et al.,* 1996).

Satheesha (2010) has quantified nectar volume in staminate and pistillate flowers of cucumber in India which confirmed that female flowers offered more

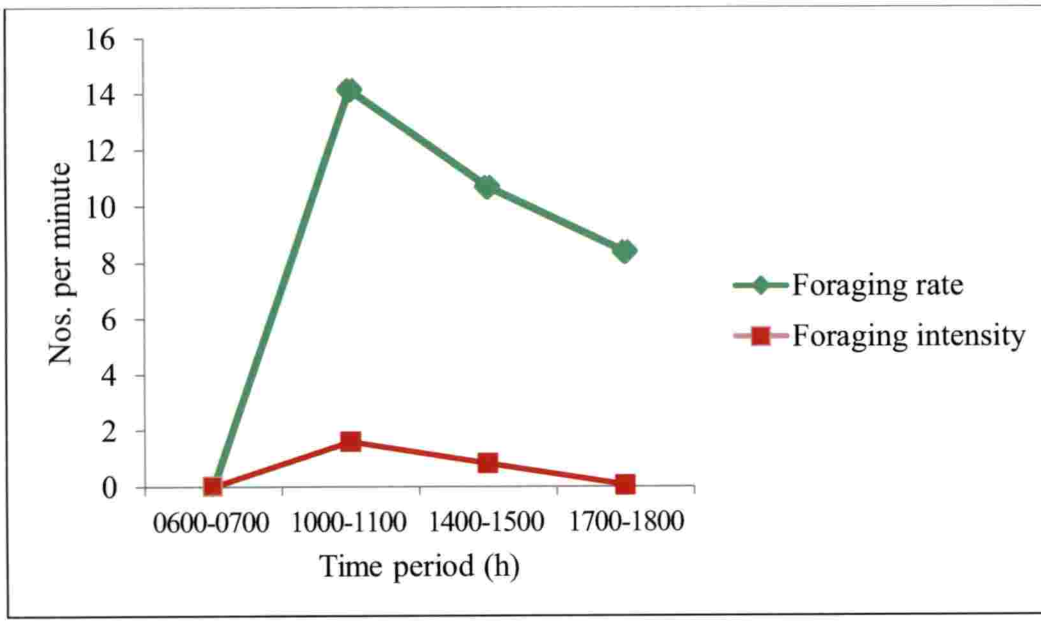


Figure 5. Foraging behaviour of honey bees (*A. c. indica*)

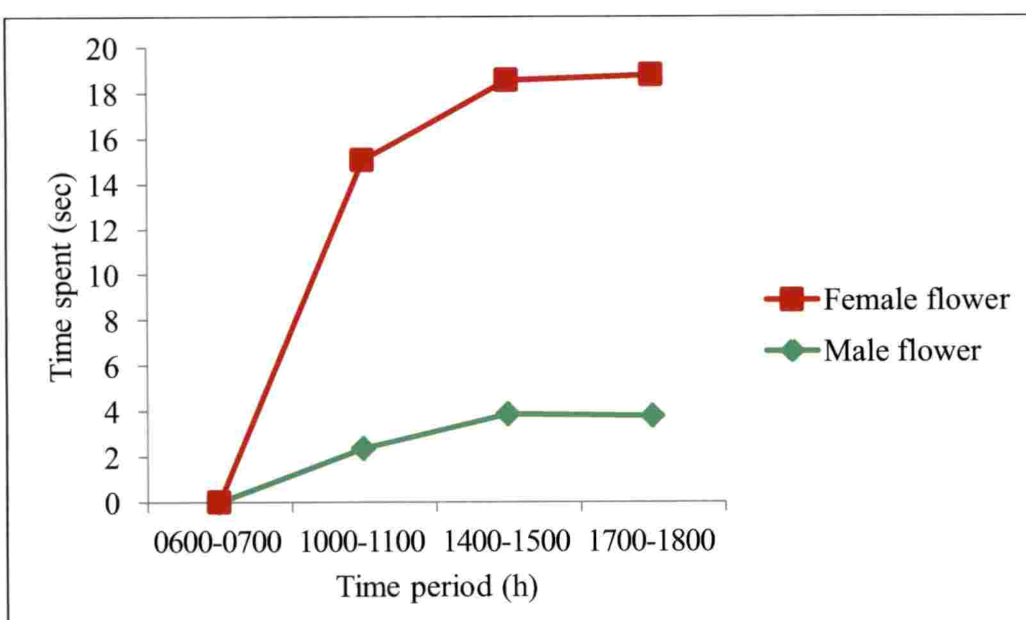


Figure 6. Time spent by *A. c. indica* on male and female flowers

nectar than male flowers. The average quantity of nectar in male flowers was recorded as 1.88 μL and that of female flowers was 2.33 μL.

Weather parameters influenced foraging behaviour of honey bees. Foraging behaviour was positively correlated with temperature whereas negative correlation was observed with relative humidity. Foraging speed increased with increasing temperature ($p < 0.05$, $r = 0.69$) and decreasing relative humidity ($p < 0.05$, $r = -0.57$). These results are in accordance with Rajkhowa and Deka (2013) in which positive relationship between foraging behaviour of honeybee and temperature ($p < 0.05$, $r = 0.69$) and non-significant negative relationship with relative humidity ($P<0.01$, $r=-0.4277$) was observed.

The temperature up to certain limit favoured the foraging activities of *A. cerana*. According to Reddy *et al.* (2015) mean monthly minimum temperature between November to April ranged from 13.50^{0}C to 20.60^{0}C which positively influenced foraging of bees. On the other hand mean monthly maximum temperature varied from 27.00^{0}C to 34.00^{0}C which influenced negatively on foraging activity of bees. The high relative humidity inactivated the pollinators and prevented the bees from foraging.

5.2 FLORAL BIOLOGY OF *C. melo var. acidulus*

The observation on floral biology indicated that stigma was receptive only on the day of anthesis and it was totally non receptive after 24 h. The results are in line with that of Premila *et al.* (2014). Stigma receptivity of culinary melon was recorded as on the day of anthesis. Loss of receptivity after one day is due to rise in temperature with advance of time which causes drying of stigma (Verma, 2017).

The results of present investigation to assess plant to pollinator relationship revealed that length of stamen (0.45 cm) of flowers and proboscis of bees (0.49 cm) were almost same and mean basal gap between stamens was 0.15 cm. This floral structure allowed the bees to work from top. The length of stamen and proboscis being same bees can work from top rather than from base of stamen. According to Schneider *et al.* (2002) top workers enhances pollination in crops. When honey bees are top workers, effectiveness of pollination is enhanced and number of top workers is the crucial aspect of the effectiveness of pollination. When the flower morphology permits only top working, pollination efficiency will be high. Top workers usually pollinate, whereas side workers do not. Loose pollen grains on the body of *A. cerana* were estimated as 7.6 X 10^5 (AICRP on HB & P, 2011-13). Top working enables adherence of pollen to bifid hairs of body which in turn enhance pollination (Tschoekea *et al.*, 2015).

5.3 STANDARDISATION OF BEE HIVES (*A. c. indica*)

A bee hive was installed at the centre of plot at 10 per cent flowering. Generally, colonies are to be introduced when 5–10 per cent of the crop is in bloom. Earlier placements of the bees result in foraging in other weeds and wild plants in the vicinity, leading to ignorance the crop bloom gradually. If bees are moved too late, they can only pollinate late and less vigorous flowers (Abrol, 2007). According to Sousa *et al.* (2014) appropriate time for introduction of beehives (*A. mellifera*) in melons is 28 days after sowing which consequently results in an appreciable yield.

The number of bees visiting blooms was high at shortest radial distance of 10 m (2.44 bees m^{-2} $min.^{-1}$) and density of bees decreased with increasing distance from hive (Figure 7), in the present study. These findings are in accordance with Kumari (2014). The foraging intensity of *A. mellifera* foragers on brassica blooms was the maximum in the proximity of the colony *i.e.* at 0 m (2.29 bees m^{-2} $min.^{-1}$) which was statistically at par with that at 20 m (2.06 bees m^{-2} $min.^{-1}$) and beyond 20 m, it decreased significantly.

Qualitative as well as quantitative parameters varied with distance from bee hive. The yield parameters were recorded as high with proximity (10 m) to bee hive (Figure 8). Maximum fruit set (75.44 %) and fruit weight (0.75 kg) was recorded at 10 m. However plants at 20 m and 30 m distances also yielded similar fruits in terms of quality and quantity. The fruit set and fruit weight was observed

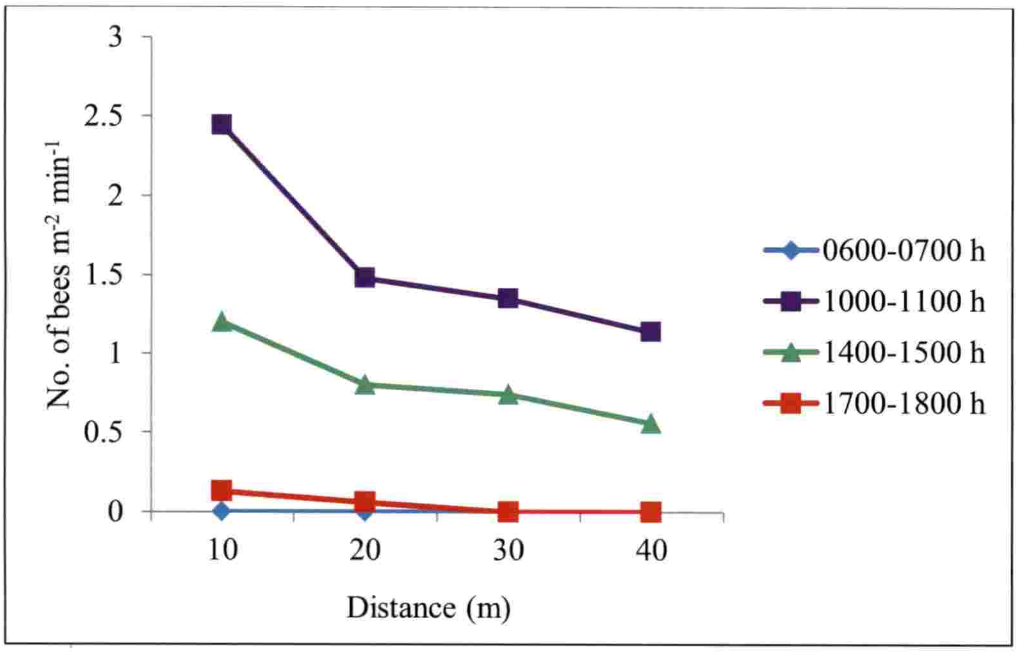


Figure 7. Foraging intensity of *A. c. indica* with varying distance

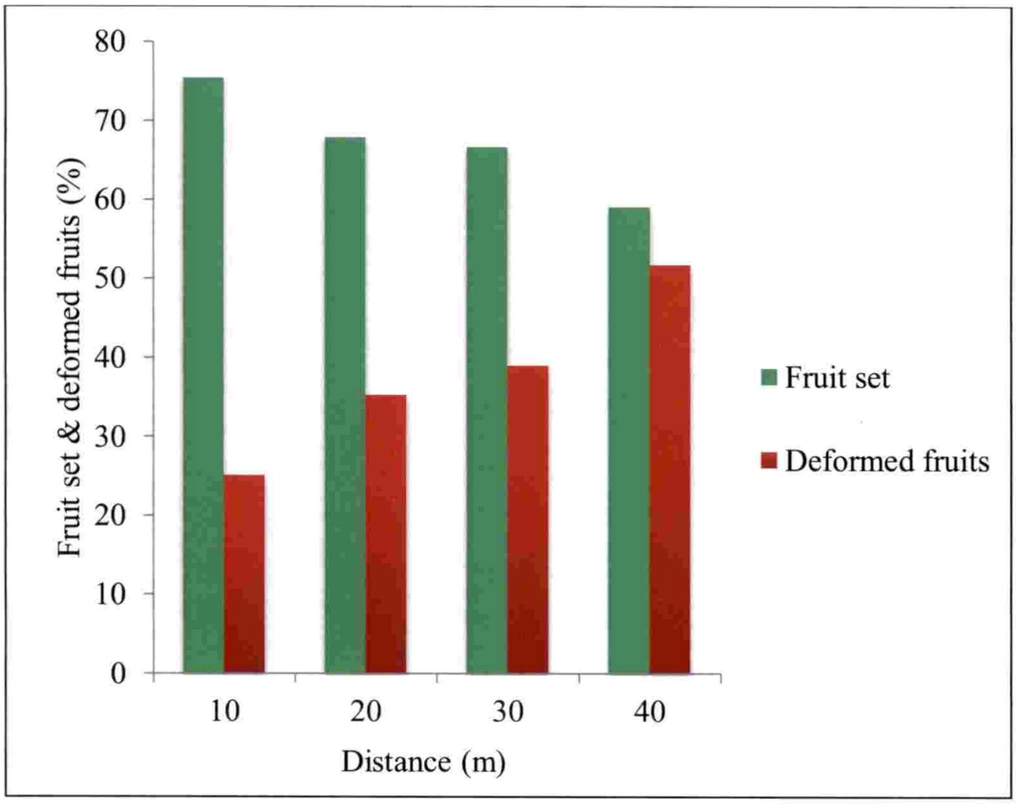


Figure 8. Qualitative parameters of culinary melon with carrying distance

as 66.62 % and 0.55 kg respectively. The other parameters *viz.*, fruit length, percentage deformed fruits, number of seeds per fruit and germination, varied (20.16-22.22 cm, 25.07 %-51.68 %, 629.50-849.50, 68.75-90.50 %) with distance. Plants at far distance (40 m) produced poor quality fruits.

Similar trend was observed in pollination of *B. napus* and *B. juncea* by *A. mellifera* (Kumari, 2014). Both in *B. napus* and *B. juncea*, maximum number of seeds per pod and seed germination was recorded at 0 m and 40 m (no. of seeds / pod- 21.05, 13.38, germination- 91.33 %, 89.33 %) which were statistically on par. Afterwards these parameters reduced significantly.

Good quality fruits at proximity to bee hive can be attributed to increased number of bees at these distances. According to Thakur and Rana (2008) as bee density increases quantity as well as quality of cucumber is improved. On an average 5.71 bees m^{-2} 10 min^{-1} visited cucumber blooms in Solan.

According to Bomfim *et al.* (2016) most cucurbits require a minimum number of pollen grains be evenly spread across all stigmatic lobes in order to develop fruit without deformities, and to achieve this, flowers should receive abundant viable pollen grains, which results from multiple pollinator visits. Frequency of bee visit decreases with distance from bee hive which consequently affected fruits, qualitatively and quantitatively.

Mc Gregor (1976) claimed that inadequate pollination may result in deformed fuits, smaller seeds which have low germination capacity as observed in onion plants. Pollination requirement of melon (*C. melo*) for optimum fruit set is minimum of twelve bee visits and 400 pollen grains as recorded by Delaplane and Mayer (2000). Reduced number of pollen grains on stigma is attributed to lower number of seeds with increasing distance from bee hive, each pollen grain being responsible for development of single seed (Hodges and Baxendale, 2007).

In the present study, number of bee hives required for adequate pollination in culinary melon (stock density) was estimated, for varying pollination ranges.

Accordingly stock density was calculated as 31.80, 7.90 and 3.50 colonies ha^{-1} for pollination ranges 10 m, 20 m and 30 m respectively. Further, benefit cost ratio including this bee hive requirement for each pollination range and its management cost was calculated. Benefit cost ratio was almost same for pollination ranges 10 m (B:C- 2.7) and 30 m (B:C- 2.5). Hence placement of 3.5 ~ 4 colonies in 1 ha is worthwhile than 31.8 ~ 32 colonies in 1 ha for adequate pollination without compromising quality, quantity and economics of production. These finding are corroborated with reports by Delaplane and Mayer (2000) wherein 4.4 colonies ha^{-1} are recommended for optimum pollination in melons. Devkota *et al.* (2016) confirmed bee keeping as effective pollination management strategy in mustard in Nepal. Deploying two frame strength colonies of *A. mellifera* in mustard fields resulted in significant B:C (1.8) which indicated higher yield and less cost of production of beekeeping contributed to higher gross return and benefit cost ratio.

The role of bee pollination in augmenting crop yield was assessed in the present study. The results revealed that all of the yield parameters were significantly higher in augmented plots ($p < 0.05$) compared to control plots without bee hives. Augmented pollination resulted in an increased yield both in terms of the quantity and quality parameters, where 57.50 per cent yield enhancement was recorded over the control plants. Similar results were obtained by Gingras *et al.* (1999) in Oka. Open plots augmented with *A. mellifera* colonies recorded 53.60 per cent yield of cucumber. According to Thakur and Rana (2008) good quality cucumber fruits in terms of high percentage healthy fruits (92.22 %), fruit weight (1184.50 g), no. of seeds per fruit (472.80) and fruit size (28.80 cm) were obtained due to caged pollination with *A. mellifera*. In Kerala, Premila *et al.* (2014) reported 25 per cent enhanced yield of culinary melon in plots caged with *A. cerana*.

In brief, the present study revealed that *A. c. indica* was dominant pollinator of culinary melon in Kerala. The peak foraging activity of bees in the crop was observed during 1000 to 1100 h with a foraging rate of 14.17 flowers $min.^{-1}$ and foraging intensity 1.60 bees m^{-2} $min.^{-1}$. Four *A. c. indica* colonies with six frame bee strength were required for adequate pollination of culinary melon in 1 ha. Augmented pollination resulted in an increased yield both in terms of the quantitative and qualitative parameters, where 57.50 per cent yield enhancement was recorded over the control plants.

Summary

6. SUMMARY

The present investigation on 'Augmentation of pollination in culinary melon (*Cucumis melo* var. *acidulus* L. Naudin) with Indian bee (*Apis cerana indica* Fab)', was conducted at Department of Agricultural Entomology, College of Agriculture, Vellayani and farmers field, Thiruvananthapuram during 2017 to 2019. The study focussed on the foraging behaviour of *A. c. indica* and standardization of number of bee hives required for yield enhancement in culinary melon is summarized below:

Preliminary observations on pollinator diversity and relative abundance of insects were carried out in standing crop of culinary melon during February to April 2019. These observations were carried out at different time periods of the day (0600 to 0700 h, 1000 to 1100 h, 1400 to 1500 h, 1700 to 1800 h) at weekly intervals during peak flowering stage of plant.

The insect fauna of culinary melon encompassed 17 insect species of pests, natural enemies and pollinators belonging to nine families under Hymenoptera, Lepidoptera, Coleoptera and Diptera. The four insect pests observed were *Bactrocera cucurbitae*, *Aulacophora foveicollis, Luperomorpha vittata* and *Spodoptera litura*. The coccinellid beetles (*Cheilomenes sexmaculata* and *Coccinella transversalis*) were the only natural enemies present in the field. The pollinators of culinary melon include *A. c. indica*, *Ceratina hieroglyphica*, *Braunaspis* sp., *C. binghami*, *C. unimaculata*, *Tetragonula travancorica, Amegilla zonata, Lampides boeticus* and *Leptosia nina.* Ants (*Camponotus* sp.) were the flower visitors. Majority of pollinators recorded belong to Hymenoptera (47.06 %) followed by Lepidoptera and Coleoptera which constituted equally (23.53 %). Least population was recorded by Dipterans (5.88 %).

Further the relative abundance of these pollinators were assessed for which, number of insects visiting flowers for five minutes in randomly selected one square metre area was recorded at different time periods from 0600 h to

1800 h. Based on the data on relative abundance dominant pollinator was assessed and its foraging behaviour was studied.

Peak population of all pollinators was recorded during 1000 to 1100 h with *A. c. indica* having highest population (12.87 bees m^{-2} 5 $min.^{-1}$) followed by *C. hieroglyphica* (1.31 bees m^{-2} 5 $min.^{-1}$). Maximum number of pollinators was recorded during 1000 to 1100 h. Afterwards the population of pollinators found to be decreasing with advance of time. The pollinators were least active during the time period 1700 to 1800 h. No pollinators foraged on blooms between 0600 to 0700 h. The observations on relative abundance revealed that *A. c. indica* was the dominant pollinator of the locality.

Foraging behaviour of *A. c. indica* was studied by observing on foraging time, foraging rate, foraging speed, foraging intensity, foraging mode and proportion of pollen and nectar gatherers. These observations indicated that the bees were nectar foragers on culinary melon. The peak activity was observed during 1000 to 1100 h. The bees commenced foraging on 0700 h and ceased activity on 1800 h, thus rendering eleven hours of foraging time. Maximum foraging rate was 14.17 flowers $min.^{-1}$ while foraging intensity was 1.60 bees m^{-2} min^{-1} during 1000 to 1100 h, thereafter the bee activity was found to be reduced. Foraging speed of bees increased with progress of time and least time spent on flowers was observed during 1000 to 1100 h. Significant difference in time spent on male and female flowers was observed. Foraging speed on male flowers fluctuated between 2.37 sec. to 3.85 sec and 12.70 to 15.00 sec. on female flowers. All bees were alighting directly on top of stigma and hence recorded as top workers.

Weather parameters influenced foraging behaviour of honey bees. Foraging behaviour was positively correlated with temperature whereas negative correlation was observed with relative humidity. Foraging speed increased with increasing temperature ($p < 0.05$, $r = 0.69$) and decreasing relative humidity ($p < 0.05$, $r = - 0.57$).

The floral biology of culinary melon was studied to assess relationship between plant and pollinator. In culinary melon flowering initiated 24 days after sowing. Anthesis occurred during 0700 to 0800 h. Female flowers were receptive only on the day of flower opening and were non receptive for remaining days. Size of staminate flowers ranged from 3.20 to 3.70 cm with mean floral size of 3.45 cm and pistillate flowers varied between 3.70 to 4.20 cm with mean floral size of 3.90 cm. Stamen length was recorded as 0.49 to 0.42 cm with a mean of 0.45 cm. Basal gap between stamens varied between 0.14 to 0.16 cm with mean basal gap of 0.15 cm. The length of pistil ranged from 2.40 to 3.00 cm with mean pistil length of 2.65 cm. These observations revealed that length of stamen (0.45 cm) and proboscis of bees (0.49 cm) were almost same which enabled top working by bees and thereby enhanced pollination through the pollen adhered on body surface of bees.

The number of hives required for optimum pollination in culinary melon was estimated by raising the crop in an area of 1 acre. Afterwards, an Indian bee hive with six frame bee strength was installed at the centre of plot at 10 per cent flowering. Four radial distances (10 m, 20 m, 30 m and 40 m) from bee hive were marked and considered as treatments. Four plants each at different distances were marked as replications. Yield parameters and foraging intensity were recorded at varying distances. The design CRD was employed for the experiment and control plot without bee hive was also maintained to compare the yield difference due to augmented pollination.

Maximum foraging intensity was recorded at shortest radial distance (2.44 bees m^{-2} $min.^{-1}$) and density of bees decreased with increasing distance from hive. The same trend was observed at all time periods of the day. Bee pollination improved quality and quantity of fruits which was recorded high at 10 m distance immediately followed by 20 and 30 m, which were on par. Plants at 40 m distance were under performing. Accordingly fruit set was recorded as 75.44 %, 67.84 % and 67.82 % at 10, 20 and 30 m distances respectively. Fruit weight was 0.75 kg at 10 m and 0.55 kg for 20 and 30 m. The other parameters recorded at these distances were fruit length (22.09 to 26.22 cm), deformed fruits (25.07 to 39 %), number of seeds per fruit (847.50 to 714.50) and germination (90.50 to 80.50 %).

Economic analysis using B:C revealed that both treatments 10 m (B:C - 2.7) and 30 m (B:C - 2.5) were economically feasible. Pollination range of 10 m needed placement of 31.8 ~ 32 colonies in 1 ha while only 3.5 ~ 4 colonies were required in 1 ha with pollination range of 30 m. Considering the economic and technical feasibility, 30 m was selected as an effective radial distance. Plants at this effective distance recorded significantly higher ($p < 0.05$) yield parameters, both quantitatively and qualitatively (fruit set - 66.62 %, fruit weight - 0.55 kg) compared to that of plots without hives (fruit set - 57.17 %, fruit weight - 0.42 kg). Thus, a yield increase of 57.50 per cent was obtained from the plot with bee hive. Deformed fruits were recorded least in augmented plots (39.00 %) than the control plot (54.91 %).

Thus the present study indicated that four *A. c. indica* colonies with six frame bee strength were required for adequate pollination of culinary melon in 1 ha. The peak foraging activity was observed during 1000 to 1100 h with a foraging rate of 14.17 flowers min^{-1}. Augmented pollination resulted in an increased yield both in terms of the quantitative and qualitative parameters, where 57.50 per cent yield enhancement was recorded over the control plants.

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AUGMENTATION OF POLLINATION IN CULINARY MELON (*Cucumis melo* var. *acidulus* L. Naudin) WITH INDIAN BEE (*Apis cerana indica* Fab.)

by

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ABSTRACT

The present study entitled 'Augmentation of pollination in culinary melon (*Cucumis melo* var. *acidulus* L. Naudin) with Indian bee (*Apis cerana indica* Fab)' was conducted at Department of Agricultural Entomology, College of Agriculture, Vellayani and at farmers field, Thiruvananthapuram during 2017 to 2019. The objectives were to study the foraging behaviour of *A. c. indica* and to standardise the number of bee hives required for yield enhancement in culinary melon.

Preliminary observations on pollinator diversity and on relative abundance of insects were carried out for assessing the dominant pollinator and to study its foraging behaviour. These observations were made at different time periods of the day (0600–0700 h, 1000–1100 h, 1400–1500 h, 1700–1800 h) at weekly intervals during peak flowering stage of plant. The floral biology of culinary melon was also studied to assess plant to pollinator relation. Culinary melon was raised in an area of 1 acre during February to April, 2019 for estimating the number of hives required per hectare for optimum pollination. For the same, an Indian bee hive with six frame bee strength was installed at the centre of plot at 10 per cent flowering. Four radial distances (T1- 10 m, T2- 20 m, T3- 30 m and T4- 40 m) from bee hive were the treatments and four plants each at different distances were considered as replications. The statistical frame work, CRD was followed for the experiment and control plot without bee hive was also maintained to compare the yield difference due to augmented pollination.

Studies on pollinator diversity revealed that the pollinators or flower visitors of culinary melon alone comprised of 14 insect species. The common pollinators observed were *A. c. indica, Ceratina hieroglyphica, Braunasis* sp., *C. binghami, Tetragoula travancorica, Lampides boeticus, Aulacophora foveicollis, Luperomorpha vittata,* and *Camponotus* sp. Maximum number of pollinators was recorded during 1000-1100 h with *A. c. indica* as the dominant pollinator (12.87 bees m^{-2} in 5 minute duration) in terms of relative abundance.

Observations on foraging behaviour of dominant pollinator, *A. c. indica* indicated that they were nectar foragers with their peak activity during 1000 to 1100 h. The bees commenced foraging on 0700 h and ceased activity on 1800 h, thus rendering eleven hours of foraging time. Maximum foraging rate was 14.17 flowers $min.^{-1}$ while foraging intensity was 1.60 bees m^{-2} $min.^{-1}$. Minimum time spent by bees was recorded as 2.37 sec. on male flowers and 12.07 sec. on female flowers. All bees were alighting directly on stigma and hence regarded as top workers.

Studies on floral biology of culinary melon revealed that female flowers were receptive only for one day. Length of stamen (0.45 cm) and proboscis of bees (0.49 cm) were almost same which enabled top working by bees and thereby enhanced pollination through the pollen adhered on the bifid hairs of bees. .

For standardising the requirement of bee hives ha^{-1}, yield parameters and foraging intensity were recorded at varying distance. Significantly high foraging intensity and yield parameters were recorded at 10 m distance (fruit set- 75.44%, fruit weight- 0.75 kg) which was immediately followed by 20 and 30 m, which were on par. Economic analysis using B:C revealed that both treatments 10 m (B:C-2.7) and 30 m (B:C-2.5) were economically feasible. Considering the economic and technical feasibility, 30 m was selected as an effective radial distance for adequate bee pollination based on which the number of hives required per ha was estimated as four. Plants at this effective distance recorded significantly higher ($p < 0.05$) yield parameters, both quantitatively and qualitatively (fruit set- 66.62 %, fruit weight- 0.55 kg) compared to that of plots without hives. Thus, a yield increase of 57.50 per cent was obtained from the plot with bee hive. Deformed fruits were recorded least in augmented plots (39.00 %) than the control plot (54.91 %).

Thus the present study indicated that four *A. c. indica* colonies with six frame bee strength were required for adequate pollination of culinary melon in 1 ha. The peak foraging activity was observed during 1000 to 1100 h with a foraging rate of 14.17 flowers $min.^{-1}$. Augmented pollination resulted in increased yield both in terms of the quantitative and qualitative parameters, with 57.50 per cent yield enhancement over the control plants.

Appendix

APPENDIX I

Benefit - cost ratio

Cost of inputs

Parameter	Per hectare requirement	Cost/unit (Rs.)	Cost (Rs.)
I. Inputs			
1.Seed	0.75kg	2000/kg	1500
2.FYM	20 tons	5/kg	100000
3.Fertilizers			
• Urea	152kg	8/kg	1216
• MOP	42kg	20/kg	840
• Rajphos	125kg	15/kg	1875
Labour	No. of labourers	Wage/men	
1.Land preparation & sowing	5	750	3750
3.Fertilizer application	4		3000
4.Spraying	1		750
Others			
1.Trap	15	150/trap	2250
2. Botanicals, Pseudomonas			350

Cost of bee hives

Sl. No.	Treatments	Per hectare requirement	Cost per unit (Rs.)	Total cost (Rs.)
1	T1	32	1500	48000
2	T2	8		12000
3	T3	4		6000
4	T4	2		3000

Cost of cultivation (1 ha)

Sl. No.	Treatments	Total cost (Rs.)
1	T1	163531
2	T2	127531
3	T3	121531
4	T4	118531
5	Control	115531

Benefit

Sl. No.	Treatments	Yield (Ton)	Gross returns (Rs.)	Net returns (Rs.)
1	T1	21.89	437800	274269
2	T2	15.01	300200	172669
3	T3	15.01	300200	172669
4	T4	11.36	227200	109669
5	Control	9.53	190600	75069

Benefit Cost Ratio

Sl. No.	Treatments	Benefit (Rs.)	Cost (Rs.)	B:C
1	T1	437800	163531	2.7
2	T2	300200	127531	2.4
3	T3	300200	121531	2.5
4	T4	227200	118531	1.9
5	Control	190600	115531	1.6