# ROLE OF FLOWER VISITORS IN BITTER GOURD (*Momordica charantia* L.) POLLINATION AND SEED PRODUCTION

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*Affectionately Dedicated*

*to Farmers*

**DEPARTMENT OF AGRICULTURAL ENTOMOLOGY**
**UNIVERSITY OF AGRICULTURAL SCIENCES**
**BANGALORE-560 065**

## CERTIFICATE

This is to certify that the thesis entitled, **"ROLE OF FLOWER VISITORS IN BITTER GOURD (*Momordica charantia* L.) POLLINATION AND SEED PRODUCTION"** submitted in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY in AGRICULTURAL ENTOMOLOGY** of the University of Agricultural Sciences, Bangalore, is a *bonafide* record of research work done by **Ms. THARINI, K. B., ID No. PAL B 3013** during the period of her study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

Bangalore
September, 2016

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Bangalore
September, 2016 **(THARINI, K. B.)**

**"ROLE OF FLOWER VISITORS IN BITTER GOURD (*Momordica charantia* L.) POLLINATION AND SEED PRODUCTION"**

**THARINI, K. B**

Studies on pollination ecology, pollinator diversity and the behaviour of pollinators in bitter gourd were carried out in the Department of Entomology, UAS, GKVK, Bangalore between 2014 and 2016. In all three seasons, flowering started 40 to 45 days after sowing and blooming period varied from 55 to 60 days. Anthesis commenced around 2.00am and continued till 8.00am with the opening of pistillate flowers followed by staminate flowers with a ratio of 18:1 (Staminate: Pistillate flowers). Staminate flowers offered rewards (nectar & pollen) for flower visitors, while the pistillate flowers were rewardless. Longevity of flowers was for one day. Pollen viability, stigma receptivity and nectar production was maximum from 10.00h to 14.00h and coincided with peak activity of pollinators (*Apis cerana* and *A. florea*). Among 27 pollinators, *A. cerana* and *A. florea* were more abundant. *A. cerana* was efficient pollinator since it visited more number of flowers per trip (310±31.07), spent less time per flower (109±9.96 seconds) and covered greater distance per unit time (72.00±6.57). Open pollination, hand pollination, green house with *A. cerana* colony and open pollination supplemented with *A. cerena* resulted in nearly 100 per cent fruit set. However, green house with *A. cerana* colony was significantly superior, showing maximum fruit weight (207.92g) and seed numbers (38.32). Similarly, the fruit weight and seed numbers in male and female lines at ratio of 1:2 of bitter gourd was significantly superior over remaining treatments in obtaining maximum fruit weight (269.38g) and seed number (37.50/fruit) with high germination per cent and more viable seeds. The estimated B:C ratio of open pollination + *A. cerana* pollination was found to be higher compared to other treatments which suggested that deployment of *A. cerana* hives in open pollination is best suited for obtaining high fruit yield and seed numbers with low cost of cultivation.

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H. Khader Khan
(Major Advisor)

## ಹಾಗಲಕಾಯಿ ಬೆಳೆಯ ಪರಾಗಸ್ಪರ್ಶ ಕ್ರಿಯೆ ಹಾಗೂ ಬೀಜೋತ್ಪಾದನೆಯಲ್ಲಿ ಪರಾಗಸ್ಪರ್ಶಕಗಳ ಪಾತ್ರ

**ಪ್ರಬಂಧದ ಸಾರಾಂಶ**

**ತಾರಿಣಿ, ಕೆ. ಬಿ.**

ಹಾಗಲಕಾಯಿ ಬೆಳೆಯಲ್ಲಿ ಪರಾಗಸ್ಪರ್ಶಕಗಳ ವೈವಿಧ್ಯತೆ, ಸ್ವಭಾವ ಹಾಗೂ ಬಿಜೋತ್ಪದನೆಯಲ್ಲಿ ಅವುಗಳ ಪಾತ್ರದ ಅಧ್ಯಯನವನ್ನು ಸನ್ ೨೦೧೪-೧೬ರ ವರೆಗೆ ಕೃಷಿ ಕೀಟ ಶಾಸ್ತ್ರ ವಿಭಾಗ, ಕೃವಿವಿ, ಜಿಕೆವಿಕೆ, ಬೆಂಗಳೂರಿನಲ್ಲಿ ಕೈಗೊಳ್ಳಲಾಗಿದೆ. ಅಧ್ಯಯನದ ಎಲ್ಲ ಮೂರು ಋತುಗಳಲ್ಲಿ, ಬಿತ್ತನೆಯಾದ ೪೦-೪೫ ದಿನಗಳ ನಂತರ ಹೂ ಬಿಡಲು ಪ್ರಾರಂಭಿಸಿದ್ದು, ಹೂ ಬಿಡುವ ಅವಧಿಯು ೫೫-೬೦ ದಿನಗಳವರೆಗೆ ಕಂಡುಬಂದಿದೆ. ಮಧ್ಯರಾತ್ರಿ ೨ ಗಂಟೆಯಿಂದ ಬೆಳ್ಳಿಗ್ಗೆ ೮ ಗಂಟೆಯ ಅವಧಿಯವರೆಗೆ ಹೂಗಳು ಅರಳಲು ಆರಂಭಿಸಿದ್ದು, ಮೊದಲಿಗೆ ಗಂಡು ಹೂಗಳು ಅರಳಿ, ನಂತರ ಹೆಣ್ಣು ಹೂಗಳು ಅರಳಿದವು. ಗಂಡು ಹೂಗಳು ಪರಾಗಸ್ಪರ್ಶಕಗಳಿಗೆ ಮಕರಂದ ಹಾಗೂ ಪರಾಗರೇಣುಗಳನ್ನೂ ಪ್ರತಿಫಲವಾಗಿ ನೀಡಿದ್ದು, ಆದರೆ ಹೆಣ್ಣು ಹೂಗಳು ಯಾವುದೇ ಪ್ರತಿಫಲ ನೀಡದಿರುವುದು ತಿಳಿದುಬಂದಿದೆ. ಹೂಗಳು ಒಂದು ದಿನದ ಜೀವಿತಾವಧಿ ಹೊಂದಿರುತ್ತವೆ. ಪರಾಗಸ್ಪರ್ಶಕಗಳ ಚಟುವಟಿಕೆಯ ಉತ್ತುಂಗ, ಹಾಗೂ ಹೂವಿನ ಮಕರಂದ ಉತ್ಪಾದನೆ, ಪರಾಗ ಕಾರ್ಯಸಾಧ್ಯತೆ ಮತ್ತು ಸ್ಟಿಗ್ಮಾ ಗ್ರಹಿಕೆಯ ಸಮಯ ಹೊಂದಾಣಿಕೆಯಾಗಿದ್ದು ಕಂಡುಬಂದಿದೆ (ಬೆಳ್ಳಿಗ್ಗೆ ೧೦ ಗಂಟೆಯಿಂದ ಮಧ್ಯಾಹ್ನ ೨ ಗಂಟೆಯವರೆಗೆ). ಗಂಡು ಮತ್ತು ಹೆಣ್ಣು ಹೂಗಳ ಅನುಪಾತವು ೧೮:೧ ಆಗಿರುತ್ತದೆ. ಒಟ್ಟು ೨೬ ಪ್ರಭೇದದ ಪರಾಗಸ್ಪರ್ಶಕಗಳು ಭೇಟಿನೀಡಿದ್ದು, ಅದರಲ್ಲಿ *ಎಪಿಸ್ ಸೆರೆನಾ* ಮತ್ತು *ಎಪಿಸ್ ಫ್ಲೋರಿಯಾ* ಹೇರಳವಾಗಿ ಭೇಟಿನೀಡಿರುವುದು ಕಂಡುಬಂದಿದೆ. ಪರಾಗಸ್ಪರ್ಶಕಗಳು ಹೆಚ್ಚಿನ ಕಾರ್ಯದಕ್ಷತೆಯನ್ನು ಹೊಂದಿದೆ ಏಕೆಂದರೆ ಪ್ರತಿ ಪ್ರಯಾಣದಲ್ಲಿ ಅಧಿಕ ಹೂಗಳ ಭೇಟಿ (೩೧೦±೩೧.೦೬), ಅತೀ ಕಡಿಮೆ ಸಮಯವನ್ನು ಪ್ರತಿ ಹೂಗಳ ಮೇಲೆ ವ್ಯಯಿಸುವುದು (೧೦೯ ± ೯.೯೬ ಸೆಕೆಂಡ್) ಮತ್ತು ಅತೀ ಕಡಿಮೆ ಸಮಯದಲ್ಲಿ ಹೆಚ್ಚು ದೂರ ಕ್ರಮಿಸುವ ಸಾಮರ್ಥ್ಯ (೭೨.೦೦ ± ೬.೫೬) ಹೊಂದಿದೆ. ನೈಸರ್ಗಿಕ ಪರಾಗಸ್ಪರ್ಶ, ಕೃತಕ ಪರಾಗಸ್ಪರ್ಶ, ಹಸಿರುಮನೆಯಲ್ಲಿ *ಎಪಿಸ್ ಸೆರೆನಾ* ಸಮೂಹ ಮತ್ತು ನೈಸರ್ಗಿಕ ಪರಾಗಸ್ಪರ್ಶಕಗಳಿಗೆ ಪೂರಕವಾಗಿ *ಎಪಿಸ್ ಸೆರೆನಾ* ಸಮೂಹವನ್ನು ಉಪಚರಿಸಿದ ಪ್ರಯೋಗದಲ್ಲಿ ಪ್ರತಿಶತ ೧೦೦ ರಷ್ಟು ಹಣ್ಣು ರಚನೆಯಾಗಿದೆ (ಫ್ರೂಟ್ ಸೆಟ್ಟಿಂಗ್). ಆದರೆ ಅಧಿಕ ಹಣ್ಣಿನ ತೂಕ (೨೦೬.೯೨ ಗ್ರಾಂ), ಬೀಜಗಳ ಸಂಖ್ಯೆ (೩೮.೩೨) ಯನ್ನು ಹಸಿರುಮನೆಯ ಜೊತೆಗೆ *ಎಪಿಸ್ ಸೆರೆನಾ* ಸಮೂಹ ಉಪಚರಿಸಿದ ಪ್ರಯೋಗದಲ್ಲಿ ಕಂಡುಬಂದಿದೆ. ಪ್ರತಿ ಎರಡು ಸಾಲು ಹೆಣ್ಣು ಹೂಗಳ ಬಳ್ಳಿಗೆ ಒಂದು ಸಾಲು ಗಂಡು ಹೂಗಳನ್ನು (೨:೧ ಅನುಪಾತ) ಬಿತ್ತನೆ ಮಾಡಿದ ಪ್ರಯೋಗದಲ್ಲಿ ಅಧಿಕ ಹಣ್ಣಿನ ತೂಕ (೨೬೯.೩೮ ಗ್ರಾಂ) ಹಾಗೂ ಬೀಜಗಳ ಸಂಖ್ಯೆ (೩೬.೫೦/ಹಣ್ಣಿಗೆ) ಪಡೆಯಲಾಗಿದೆ. ನೈಸರ್ಗಿಕ ಪರಾಗಸ್ಪರ್ಶಕತೆಯ ಜೊತೆಗೆ *ಎಪಿಸ್ ಸೆರೆನಾ* ಸಮೂಹದ ಸಹಾಯದಿಂದ ಕಡಿಮೆ ಸಾಗುವಳಿ ವೆಚ್ಚದಲ್ಲಿ ಅಧಿಕ ಇಳುವರಿ ಮತ್ತು ಬೀಜೋತ್ಪಾದನೆ ಸಾಧಿಸುವಲ್ಲಿ ಈ ಪದ್ಧತಿ ಸಫಲವಾಗಿದೆ.

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ಡಾ. ಹೆಚ್. ಖಾದರ್ ಖಾನ್

(ಪ್ರಧಾನ ಮಾರ್ಗದರ್ಶಕರು)

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# I INTRODUCTION

Bitter gourd (*Momordica charantia* L.) is one of the most popular, annual tropical vegetable crops probably originated in South East Asia. It is widely grown in India, Indonesia, Malaysia, China and tropical Africa. It is a monoecious climbing type herbaceous crop belonging to the family Cucurbitaceae, which consists of 130 genera and 900 species. Depending on the location, it is known by different names- balsam pear, bitter melon, bitter cucumber and African cucumber (Heiser, 1979).

Being one of the most important vegetable crops grown in India it is cultivated in an area of 78.89 lakh ha with an annual production of 807.47 lakh tonnes and a productivity of 197.66 tonnes/ha. In Karnataka, it occupies an area of 3.13 lakh ha with the annual production of 34.14 lakh tonnes and the productivity of 10.9 tonnes/ha (Anon., 2015).

Bitter gourd is an excellent source for vitamin C & A, phosphorus, protein, thiamin, calcium, and iron. Leaf juice is used for curing cough, as a purgative and as an anti-helminthic to expel intestinal parasites and for healing wounds. It also contains beta-carotene, a hypoglycemic polypeptide and plant insulin responsible for lowering of blood sugar (Behera, 2008). The fruits of bitter gourd are utilized in many ways, more commonly as fried, boiled, stuffed or cooked in curries (Choudhury, 2000).

*Momordica* species grow well in hot humid areas of tropical and subtropical climates. It is mainly cultivated during spring, summer and rainy seasons with some winter production in subtropical climates. In contrast, it is being cultivated throughout the year in tropical climates. It performs very well in full sun and is adaptable to a wide range of soil types but grows best in a well-drained sandy loam soil that is rich in organic matter (Reyes *et al*., 1994).

Bitter gourd being monoecious in nature, male and female flowers are borne at different positions on the same plant. The plant is a fast growing, trailing or climbing vine with thin stems and tendrils. The leaves are heart-shaped, 5-10 cm in diameter, cut into 5-7 lobes. Flowers are borne singly in the leaf axils. Male flowers appear first and usually exceed the number of female flowers by about 20:1. The flower opens at sunrise and remains open for only one day (Subhakar *et al*., 2011).

In most of the cucurbit crop species, staminate flowers offer nectar and pollen, while the pistillate flowers offer only nectar as floral rewards to pollinators (Free, 1993). In some plant species like cucumber (*Cucumis sativus* L.), squash (*Cucurbita pepo* L.) and zucchini (*C. maxima* L.), pistillate flowers produce more nectar per flower than the staminate flowers and therefore, attract more pollinators (Nepi *et al.*, 1996). However, in some crops like bitter gourd (*M. charantia*), ridge gourd (*Luffa acutangula* L.) and bottle gourd (*Lagenaria vulgaris* L.) pistillate flowers are rewardless (Bahadur *et al.*, 1986). These rewardless pistillate flowers mimic the staminate flowers and are in most cases pollinated by deceit (Baker, 1976).

Globally, 264 crop species have been identified as being dependent or partially dependent on pollination. Worldwide, out of 124 leading food crops 87 crops rely mainly on animal pollination (Klein *et al.*, 2007). To adequately evaluate the importance of animal pollination for plant products in our food supply, and for economic analyses of crop pollination by animals, we need a global review of crops considering their breeding systems, their flower visiting fauna and the level of production increase resulting from animal visitation and pollination, as supported by experimental evidence (Kevan & Phillips, 2001). In fact, 39 of the world's most produced 57 crop species exhibit an increase in yield due to biotic pollination. Between 15 and 30 per cent of food consumed by humans in developed countries requires an animal pollinator. Insect pollinators play a crucial role in effective pollination of many crops and thus contributing to both increased productivity and quality. In tropics, insect pollination increases fruit and seed production in 70 per cent of the crops (Roubik, 1995). According to The Economics of Ecosystems and Biodiversity (TEEB) report (2010), the total economic value of insect pollination globally is estimated to be €153 Billion, which equates to 9.5% of agricultural production.

The open nature of bitter gourd flowers makes them easy for the pollinators to access and exploit floral rewards from male flowers. The high male to female ratio achieves the production of sufficient amount of pollen deposits, thus resulting in effective pollination. A successfully pollinated flower starts to develop fruit from second to fifth day after it had opened, while un-pollinated flowers dry up and the ovary turns yellow on fifth day (Deyto and Cervancia, 2009). The lack of pollination can be a major limiting factor, because inadequate pollination can result not only in reduction of yield but also in delayed yield with a high percentage of inferior fruits (Mc Gregor, 1976). The insects of Apidae are the most reliable agents for pollination. Among the members of Apidae, honey bees are of particular importance as they are capable of carrying pollen and in the process, the plants visited by them are benefited. Since bitter gourd is highly cross-pollinated, honeybees are chief insect pollinators for this crop. For better fruit set and higher seed yield, honeybees should be in abundance in the field at the time of flowering (Sirohi, 1997). However, the global stock of domesticated honey bees is growing slower than agricultural demand for pollination (Tewari and Singh, 1983).

Literature on decline of pollinators worldwide has prompted a growing interest in the importance of pollinator diversity in both natural and crop ecosystems (Buchmann and Nabhan, 1996; Kevan, 1999). Therefore, the conservation and management of insect pollinators is gaining importance day by day for which studies on the floral biology in relation to pollinators, pollinator diversity and abundance, species richness, pollination success, fruit set and seed production are essential in bitter gourd. Hence, the present investigation was taken up to generate information about bitter gourd at the Department of Entomology, College of Agriculture, University of Agricultural Sciences, Bangalore, with the following specific objectives.

1. To study the floral biology, flowering phenology, diversity and abundance of flower visitors in bitter gourd and

2. To study the effect of pollinators on seed production of bitter gourd in open and protected cultivation.

# II REVIEW OF LITERATURE

The literature pertaining to the present study on "Role of flower visitors in bitter gourd (*Momordica charantia* L.) pollination and seed production" has been reviewed in the present chapter. The available literature has been classified and presented under different headings such as bitter gourd and its floral biology, floral traits and flower visitors, foraging behavior of pollinators and its importance in enhancing fruit set and role of pollinators in seed production. Since, the available literature on bitter goud is scanty, the review on the subject of pollination has been presented in general, covering the various aspects of pollination biology of cucurbit crops.

## 2.1 Bitter gourd and its floral biology

Pal *et al.* (1976) studied the floral biology of *M. charantia* and showed that bitter gourd vines started flowering 40 days after sowing and blooming period varied from 68 to 76 days. The male flower buds took an average of 17 to 19 days, whereas female buds took 21 to 22 days for their complete development. The anthesis started at 04.00h and continued till 07.30h. The male flowers dropped off on the same day at 06.00 to 07.00h, while female flowers withered away next morning. Pollen grains of bitter gourd were round in shape with three distinct germpores. The stigma receptivity was found to be maximum at the time of anthesis, beginning from eight hours before anthesis and continued upto 12 hours after anthesis.

Pillai *et al.* (1978) observed that pistillate flower of bitter gourd consisted of inferior ovary and a three-lobed, wet stigma that was attached to a columnar, hollow style. The ovary contained three carpels, each with 14 to 18 ovules, surrounded by an ovary wall. Although the number of ovules in an ovary was upto 60, the average was 40.

Snake gourd anthesis began between 17.15 and 19.45h and continued untill 21.30 h in South Canara Local, whereas in Bengaluru Local it occurred between 04.00 and 07.30h. Anther dehiscence in both species occurred before flower opening, taking about 1 hour. The stigma was receptive from 12 hour before to 12 hour after anthesis, with a peak at the time of anthesis (Deshpande *et al.,* 1980).

Shikhalia *et al.* (1990) observed that spine gourd (*M. dioica*) contained both staminate and pistillate flowers and both were solitary and light yellow in colour. Pistillate and staminate buds took 9 and 11 days, respectively, to reach anthesis. Anthesis in both types of flowers commenced at 19.00h and was completed by 20.00h with a peak at 19.40h, anther dehiscence began at 18.00h and continued up to 19.00h with a peak at 18.40h. The pollen grain was round and yellow with 3 germpores. Pollen viability was 97.87 per cent initially and then decreased with time with increasing room temperature and RH. Addition of boric acid to sucrose and glucose media increased percentage pollen germination and pollen tube length. Stigmas were receptive from 12 hour before to 18 hour after anthesis with a peak at the time of anthesis.

Hemanth Kumar (2006) reported that pumpkin produced three to four lateral branches and each lateral branch bear 48 to 69 flowers. The pistillate to staminate flower ratio was 1:3. The flowers were lemon yellow to deep orange in colour. The flowers opened at 07.00h and remained open upto 11.00h, anther dehiscence was also commenced at 07.00h.

Manjula (2007) opined that summer squash (*Cucurbita pepo* L.) was an annual herbaceous, non-vining bush plant. Each leaf axil had produced both staminate and pistillate flowers separately on the same plant at the ratio of 3:1. The flowers were lemon yellow to deep orange in colour. The flowers started opening at 07.00h and staminate flowers remained open upto 14.00h and pistillate flowers remained open upto 18.00h. Anther dehiscence started immediately after the opening of the flower at 07.00h.

Each lateral branch of ridge gourd had produced 68 to 75 flowers in leaf axils. Staminate and pistillate flowers were yellow in colour and opened at 16.00 to 18.00h, but staminate flower opened few hours earlier than pistillate flowers and remained open upto 11.00 to 12.00h of next day, whereas pistillate flowers remained open upto 16.00 to 18.00h of the next day. Anther dehiscence occurred alongwith the opening of the flower (Ramesh, 2007).

Agbagwa *et al.* (2007) observed that both male and female flowers in winter squash (*C. moschata*) began opening between 03.30 and 04.00h. The male flower opened from 08.00 to 09.00h and the female opened from 06.30 to 07.00h, there was, however, a period of overlap in the anthesis of both sexes, which coincided with the peak of pollen viability and pollinator activity. Pollen viability was about 90 per cent in newly opened flowers but decreased to 62 per cent on closure and crashed to 8 per cent after 1 day. Stigma receptivity, measured by pollen germination on the stigma, lasted for 1 day before and 2 days after the anthesis.

Rubina (2010) reported that each lateral branch of cucumber (*Cucumis sativus* L.) had produced 42 to 48 flowers in leaf axils and staminate and pistillate flowers occurred separately on the same plant in the ratio of 6:1. The flowers were bright yellow in colour. The flowers opened at 07.30 h and remained open upto 16.00h in staminate and 18.00h in pistillate. Anther dehiscence commenced at 07.30h, immediately after the opening of flower.

Srikanth (2012) noted that in bottle gourd, *Lagenaria siceraria* Molina Standl., both staminate and pistillate flowers were borne on the same plant in leaf axils in the ratio of 2:1. Both staminate and pistillate flowers were white in colour. The flowers opened between 16.00 and 18.00h *i.e.*, in the evening hours. Staminate flowers opened few hours earlier than pistillate flowers and remained open upto 11.00h of next day whereas, pistillate flowers remained open till 18.00h on the same day. Anther dehiscence occurred along with the opening of flower.

The bitter gourd flowers started opening 45 days after germination with the staminate flowers appearing first followed by rewardless pistillate flowers. The ratio of pistillate to staminate flowers was 1: 13 (Mary *et al*., 2012).

Naik *et al.* (2013) examined that the time required by male and female flower buds of teasel gourd (*M. dioica*) to reach anthesis was 15 and 10 days, respectively. Opening of either type of flowers occurred between 06.00 and 07.00h and dehiscence of anthers began at time of opening of female flower. The stigma became receptive 12.00h before anthesis.

Revanasidda (2015) opined that muskmelon (Arka Jeet variety) flowers opened 42-43 days after planting. Longevity of both the flowers lasted for one day. Staminate flowers opened between 05.45-07.00h and 06.30-07.45h, hermaphrodite flowers opened between 07.00-08.30h and 07.45-09.00h in post monsoon and summer seasons, respectively. Anther dehiscence in both the flowers occurred 10-15 minutes after anthesis. The staminate and hermaphrodite flowers were observed in the ratio of 18:1.

## 2.2 Floral traits and Flower visitors

Batra (1967) reported that *Apis florea* Fab. visits more number of flowers in *C. maxima* L. as against *A. dorsata* Fab. The other pollinators such as *Lasioglossum cattulum* Vachal, *L. massuricum* Bluth, *Nomia oxybeloides* Smith, *Nomioides minutissima* Rossi, *N. variegate* Oliver and *N. divisa* Cameron were in negligible numbers.

Seyman *et al.* (1969) highlighted the importance of bees for the pollination of cucurbitaceous crops and reported that honey bees were extremely important for the pollination of cucumber.

Atwal (1970) recorded more than 23 species of bees visiting flowers of cucurbitaceae in Ludhiana. Of the various bees, the most abundant species visiting the flowers were *A. dorsata* F. followed by *A. florea*, *Ceratina binghami* Cockerel, *Xylocopa pubescens* Spinola, *Nomioides* sp. and Halictine bees. Kapil and Chaudhury (1974) also showed that of the total bee populations foraged on cucurbit flowers from June to September, *A.florea* Fab. constituted 33.10 per cent followed by *Nomia* sp. (21.30 %), *Halictus* sp. (19.30 %), *Pithitis* sp. (11.30 %), *Nomioides* sp. (8.30 %) and *Xylocopa* sp. (6.00 %).

Among social bees, *A. florea* and *A. dorsata* constituted 70.70 and 77.20 per cent of the total number of bees collected from *C. pepo* in 1974 and 1975, respectively at Ludhiana. Among the solitary bees, *Pithitis smaragdula* Fab (10.8 %) was more abundant during 1974 and *X. fenestra* Fab. (7.30 %) during l975 (Grewal and Sidhu, 1979).

Girish (1981) observed that *Apis* spp. *viz.*, *A. cerana*, *A. dorsata* and *A. florea* were the most important pollinators of summer squash which contributed 87, 10 and 3 per cent, respectively near Bengaluru.

Mohan Rao and Suryanarayana (1988) examined insects visiting watermelon and recorded honey bees, solitary bees and few dipterans. Of the honey bee species, *A. cerana* (87 %) was the principal resource partitioner at Vijayarai and found to be more efficient pollinator than *A. florea* and *T. iridipennis*.

Shrivastava (1990) made observations on pollination of bottlegourd (*L. siceraria* Mol.) standl.), ridge gourd (*Luffa acutangula* Roxb.), wild bitter gourd (*M. diocia* L.) and wild pointed gourd (*Trichosanthes cucumerina* Roxb.) and found that these gourds were pollinated by the bug, *Cyrtopeltis tenuis,* sphingid moths, pyralid moths and the ladybird beetle, *Epilachana punctata* Fab.

Shrivastava and Shrivastava (1991) studied 23 species of insects visiting cucurbitaceous crops in Rewa (India). White flower gourd/bottle gourd (*L. siceraria* Standl.) was visited by *X. fènestrata* Fab. for pollen and nectar and was considered as a good pollinator (Sihag, 1990 and Sihag, 1993).

Eswarappa (2001) reported that chow-chow crop was visited by 26 insect species, of which 14 belonged to Hymenoptera and four each to Diptera, Lepidoptera and Coleoptera. *A. dorsata*, *A. cerana*, *A. florea* and *T. iridipennis* comprised more than 82 per cent of the total insect pollinators of the crop. Prakash (2002) also made similar observations on cucumber and revealed that cucumber was visited by 27 insect species, of which 16 belonged to Hymenoptera and four each to Diptera, Lepidoptera and Coleoptera. The hymenopterans (*A. dorsata*, *A. cerana*, *A. florea* and *T. iridipennis*) comprised more than 82 per cent of the total insect pollinators.

Sajjanar *et al.* (2004) reported 24 flower visitors on cucumber, of which 14 belonged to Hymenoptera, four to Diptera, two to Coleoptera and four to Lepidoptera. Among the honey bee species, *A. dorsata* was the most frequent visitor, followed by *A. cerana*, *T. iridipennis* and *A. florea.*

Nidagundi and Sattagi (2005) reported that among the 10 species of pollinators in bitter gourd, *A. florea* was the most predominant, constituting 43.00 per cent of the total pollinators, followed by *A. cerana* (26.00 %), *A. dorsata* (13.00 %) and other pollinators (18.00 %).

Hemanth Kumar (2006) demonstrated that pumpkin flowers were visited by 16 species of insects, of which eight species belonged to Hymenoptera, three each to Diptera and Coleoptera and two to Lepidoptera. Honey bee species *i.e., A. cerana indica* and *A. dorsata* constituted more than 98 per cent of the total insect visitors.

Summer squash flowers were visited by 22 species of insect pollinators, of which 15 species belonged to Hymenoptera, five to Diptera and two to Lepidoptera. Honey bee species *i.e., A. cerana, A. florea* and *A. dorsata* constituted more than 80 per cent of the total insect pollinators (Manjula, 2007).

Ramesh (2007) observed that ridge gourd flowers were visited by 21 species of insects, of which 12 species belonged to order Hymenoptera, four to Diptera, three to Coleoptera and two to Lepidoptera. Honey bee species *i.e., A. cerana, A. florea* and *A. dorsata* constituted more than 78 per cent of the total flower visitors. Leonie *et al.* (2009) reported that *C. melo* subsp. *agrestis* is probably pollinated by several Hymenoptera, principally by *Hypotrigona para*.

Deyto and Cervancia (2009) observed the pollinator species of bitter gourd (*M. charantia*) and found that honey bees (*A. mellifera* and *A. cerana*), stingless bees (*Trigona* spp.) and *Halictus* spp. were the major insect pollinators. Mary *et al*. (2012) showed that species of pollinators of bitter gourd included Honey bees (*A. mellifera*), *Plebeina hildebrandti* Friese, *Lasioglossum* sp. and Carpenter bees (*Xylocopa* spp.).

Rubina (2010) showed that cucumber crop was visited by 28 species of insect pollinators during flowering, of which 20 species belonged to order Hymenoptera, two to Diptera, four to Coleoptera and two to Lepidoptera. Honey bee species *viz.*, *A. cerana*, *A. florea* and *A. dorsata* constituted more than 84 per cent of the total insect pollinators.

According to Subhakar *et al.* (2011) a total of 17 species belonging to ten families of four orders *viz.*, Hymenoptera, Lepidoptera, Diptera and Coleoptera were recorded foraging on bitter gourd. Among these, *T. iridipennis* Smith, *H. gutturosus* Vachal and *A. florea* were the most frequent.

Srikanth (2012) reported that bottle gourd crop was visited by 18 species of insect pollinators during flowering, of which eight species belonged to Hymenoptera, five to Diptera, two to Coleoptera and three to Lepidoptera. Honey bee species, *A. dorsata* constituted more than 23 per cent of the total insect pollinators.

Ridge gourd flowers were visited by 33 species of insect pollinators. Among them, 22 species belonged to Hymenoptera, five to Diptera, four to Coleoptera and two to Lepidoptera. Honey bees constituted 76.46 per cent of total flower visitors (Swarajya Lakshmi, 2013).

According to Bodlah and Waqar (2013), Hymenoptera and Diptera were identified as the major pollinators of ridge gourd (*L. acutangula*), bitter gourd (*M. charantia* L.) and eggplant (*Solanum melongena* L.). The order Hymenoptera included six species (*Apis* sp., *Bombus* sp., *Xylocopa* sp., *Halictus* sp. and two unidentified species 1 from Halictidae and 1 from Megachilidae) and order Diptera included 3 species (*Eristalinus* sp. and 1 un-identified species from family Syrphidae and Muscidae each). Ridge gourd had the highest number of flower visitors followed by bitter gourd and eggplant.

Hanh *et al.* (2014) reported 24 insect species visiting cucumber flowers at Hisar (Haryana) which constituted 12 hymenopterans, 6 lepidopterans, 3 dipterans, 2 hemipterans and 1 coleopteran. Among these, *Halictus* sp., and *A. dorsata* were dominant. Shubhakar and Shreedevi (2015) reported that *Halictus* sp. was the main pollinator of cucumber flowers.

### 2.3 Foraging behaviour of effective pollinators

Variations in visits by honey bees occur between plants sometimes only a few feet apart, if there is a variation in the microclimate around the plants. This means that some flowers receive more visits than necessary which all flowers are expected to receive an optimum number of visits (Whitaker and Bohn, 1952). Mc Gregor and Todd (1952) also reported that the bee activity begins on the flower shortly after it opens, reaches a peak at about 11 am and ceases by about 5 pm in cucurbit crops.

Mann (1953) recorded that the perfect flowers of cantaloupe were visited by honey bees with an average of 53 times and 42 times for staminate flowers. This frequency difference might be associated with the larger corollas of perfect flowers; these averaged 1.3 times the diameter of corollas of staminate flowers. Bees remained on perfect flowers an average of 1.5 times longer than on staminate flowers. Individual perfect and staminate flowers produced about equal quantities of pollen, ranging from 8 to 13 thousand grains. During the day, bees removed all but 2 thousand of these pollen grains. Pollen removal was most rapid during the morning hours.

A number of workers claim to ensure cucumber pollination on yield parameters with eight bee visits per flower (McGregor *et al.*, 1965 and Conner, 1969). Stephen (1970) reported that *Halictus* sp. made an average of eight visits per blossom that was required to yield uniform sized cucumber.

Sanduleac (1959) observed that honey bees work on the cucurbit flowers (*C. pepo*, *C. maxima* and *C. moschata*) most intensively from 06.00 to 12.00 h with a maximum activity from 08.00 to 09.00 h in Rumania. Honey bees worked on the staminate flowers more vigorously than the pistillate flowers.

Shemetkov (1960) from Russia and Nemirovich-Danchenko (1964) from Siberia reported that bees collected nectar from cucumber flowers between 10.00 and 12.00h. Both pistillate and staminate flowers produced nectar and were attractive to honey bees in cucumber (Conner, 1969).

In Wisconsin, honeybees collected nectar throughout the day from cucumber flowers with peak activity during 11.00 to 14.30h (Kauffeld and Williams, 1972). Whereas, Italian honeybee, *A. mellifera* collected nectar from both staminate and pistillate flowers of cucumber and spent more time on pistillate flowers compared to staminate flowers. Majority of bee visits (80.0 %) was between 09.00 and 14.00h with a preference to pistillate flowers before 09.00h followed by staminate flowers (Collison, 1973).

Girish (1981) observed that during February, *A. cerana* began foraging on summer squash at 06.20h, whereas *A. dorsata* and *A. florea* appeared about 2 hour later and all species ceased foraging by 12.00h.

Mohana Rao and Suryanarayana (1988) stated that *A. cerana* was the principal pollinating insect and found to be efficient pollinator than *A. florea* and *T. iridipennis* in watermelon. Further, *A. florea* activity was maximum at 09.00h as the pollen gatherers were maximum during this period and also recorded that during pollen collection in watermelon, *A. cerana* spent 1.40 to 6.90 seconds on each staminate flowers. They spent less time in the early hours and the time spent steadily increased up to 11.00h during that time pollen availability decreased.

Sattigi *et al.* (1996) reported that, in general foraging activity of honey bees was noticed throughout the day, but peak activity was observed between 08.00 to 11.00h in winter, 06.00 to 11.00h and 16.00 to 18.00h in summer and 08.00 to 12.00h in monsoon irrespective of the crops in transitional area. The foraging activity was low during other times of the day in different seasons. Seyman *et al.* (1969) opined that honey bees are extremely important for the pollination of cucumber crop and the major portion of bee pollination activity occurs during the midday period.

The activity of different species of honeybees either in open plots or caged plots of chow-chow was found to be maximum at 10.00 to 11.00h and lowest at 06.00h (Eswarappa, 2001). He also reported that the peak pollen foraging activity was at 10.00h and the time spent by different honeybee species for collection of pollen was maximum between 08.00 and 09.00h. Among the honeybees, maximum time spent in collection of pollen was by *A. florea* (14.63 sec.), followed by *T. iridipennis* (12.89 sec), *A. cerana* (7.59 sec), *A. mellifera* (6.77 sec.) and least in *A. dorsata* (5.77 sec.).

Sajjanar *et al.* (2004) observed that *A. dorsata* bees spent 27.5 to 41.69 sec/flower on pistillate flowers for nectar collection during different hours of the day, whereas *A. cerana* spent 32.75 to 47.69 sec/flower in cucumber. However, *A. florea* and *T. iridipennis* spent comparatively longer time (325.75 to 379.83 and 258.38 to 329.25 sec/flower) during different day hours. On staminate flowers, nectar foragers of *A. dorsata* spent 26.13 to 38.00 sec/flower and *A. cerana* between 30.44 to 43.44 sec/flowers whereas, *A. florea* spent from 306.31 to 340.75 sec/flower and *T. iridipennis* between 279.25 and 303.31 sec/flower. According to McGregor *et al.* (1965) honey bee had visited each flower at every 15 minutes interval which was desirable for maximum fruit set in cantaloupe. They calculated that one bee for each 10 hermaphrodite flowers was necessary to provide this rate of visitation. Adlerz (1966) observed that *A. mellifera* spent more time on pistillate than staminate flowers in watermelon for nectar.

Nidagundi and Sattagi (2005) reported that among the total visiting pollinators, *A. florea* was the most predominant species constituting 43.00%, followed by *A. cerana* (26.00%), *A. dorsata* (13.00%) and others (18.00%) and the peak foraging activity of *A. cerana* and *A. dorsata* was observed at 12.00h with 6.68 and 15.44 bees/$m^2$/5 minutes, respectively. Deyto and Cervancia (2009) revealed that *Halictus* sp. spent more time (26.46s) than *Trigona* sp. (23.23s) whereas *Apis* sp. spent less time (5-6s).

The foraging activity of bees on bitter gourd started around 08.00 h and continued upto 18.00h at 10 per cent flowering. *A. dorsata* and *A. florea* were observed foraging from 08.00 to 18.00h of the day, with highest foraging activity at 12.00h with 6.68 and 15.44 bees/$m^2$/5 min., respectively. But the activity of *A. cerana* and other pollinators was maximum at 10.00h, with 12.51 bees/$m^2$/5 min and 6.39/$m^2$/5min (Nidagundi and Sattagi, 2005).

In pumpkin, quantity of nectar gradually increased with the advancement of time and reached maximum at 09.00h in both pistillate and staminate flowers and thereafter, nectar secretion declined (Hemanth Kumar, 2006). Whereas, in summer squash, Manjula

(2007) showed that quantity and sugar concentration of nectar was more in pistillate flowers (13.33 µl and 40.59 per cent, respectively), compared to staminate flowers (9.92 µl and 38.28 %, respectively). The quantity and sugar concentration of the nectar increased with the advancement of time and reached maximum at 0900 h and thereafter, the nectar secretion decreased.

Ramesh (2007) demonstrated that quantity of nectar gradually increased with the advancement of time and reached maximum at 09.00h in both pistillate and staminate flowers of ridge gourd. The quantity of nectar and its sugar concentration in Arka Sumeet and Arka Sujath was more in pistillate flowers 5.54 µl and 36.61 per cent and 5.24 µl and 35.47 per cent, than in staminate flowers 5.07 µl and 26.24 per cent and 4.91 µl and 25.83 per cent, respectively.

Pateel and Sattagi (2007) recorded that *A. florea*, *A. cerana* and *A. dorsata* were the most frequent insect pollinators visiting the *rabi* cucumber flowers in Karnataka with 8.03, 6.03 and 3.43 bees/$m^2$/5 minutes, respectively.

Nicodemo *et al*. (2009) reported that *Trigona* sp. spent a mean time of 60.50s per flower in Brazil. Maximum time spent by *Trigona* sp. on a flower could be related to lower visitation rates in terms of energy kinetics. Higher visitation rates coupled with moderate foraging speed of *Halictus* sp. and *Apis* sp. (9.00 and 11.00s/flower, respectively) contributed to effective pollination qualities.

Bitter gourd, watermelon, cucumber, and luffa crops were visited by stingless bees, which were only a small proportion of the complex of visitors (Heard, 2009).

In cucumber, the quantity of nectar and sugar concentration gradually increased with the advancement of time and reached maximum at 15.00h in both male and female flowers and thereafter, decreased towards the end of the day. The quantity of nectar was more in female flowers (2.34 µl) than in male flowers (1.80 µl) but the sugar concentration was more in male flowers (37.31 %) than female flowers (31.40 %). Similarly, peak nectar foraging activity of honey bees was found at 12.00h of the day and the time spent by different honey bee species in collection of nectar from pistillate and staminate flowers was found to be maximum at 13.00h in cucumber. The maximum time spent by *A. florea* (306.30 sec $flower^{-1}$), followed by *T. iridipennis*, *A. dorsata* and *A. cerana* with a mean time spent of 295.32, 36.07 and 35.65 sec/flower, respectively (Khaja Rubina, 2010). Pavan Kumar (2010) stated that *Trigona* sp. spent maximum time on a bitter gourd flower followed by *Halictus* sp. and *A. florea*.

Subhakar *et al.* (2011) reported that foraging activity in bitter gourd was maximum (9.22-8.17 bees/$m^2$/5 minutes) at 09.00-10.00h. Foraging activity of *T. iridipennis, A. florea* and *H. gutturosus* commenced at 06.00, 06.30 and 07.30h respectively, with peak at 09.00-10.00h and ceased by 14.00, 12.30 and 13.00h respectively.

On a single foraging trip, *A. cerana* foragers tend to collect either pollen or nectar (not both) from a single species of plant, continuing to collect pollen or nectar from that plant throughout the day (Corlett, 2011). Muskmelon flower was attractive to bees for both pollen and nectar. Collection of pollen by bees usually ended before noon, but nectar collection continued to late afternoon.

According to Srikanth (2012) quantity and sugar concentration of nectar was more in female flowers 43.70 µl and 48.60 per cent respectively, compared to male flowers 28.60 µl and 27.40 per cent respectively in bottle gourd. The quantity and sugar concentration of the nectar increased with the advancement of time and reached maximum at 18.00h and thereafter, the nectar secretion decreased.

Swarajya Lakshmi (2013) reported that the maximum foraging activity of *A. cerana*, *A. florea* and *T. irripennis* in ridge gourd was between 09.00 and 11.00h of the day, whereas the other pollinators were observed between 12.00 and 16.00h. The time spent for nectar and pollen foraging by *A. cerana*, *A. florea* and *T. irridipennis* was maximum at 09.00 and 11.00h of the day. Bodlah and Waqar (2013) also recorded much higher foraging rate in the early morning *i.e.*, 06.00 to 07.00h in ridge gourd, bitter gourd and eggplant. Hisar and Pavan Kumar (2010) observed that the foraging rate of *Halictus* sp. varied from 4.05 to 8.65 flowers during different hours of the day in bitter gourd.

Similar to these, the studies made by Shubhakar and Shreedevi (2015) revealed that *T. iridipennis* started the foraging activity at 06.00 h of the day and its mean number increased upto 10.00 h and thereafter declined with maximum foraging activity at 09.00 h (24.41 bees/$m^2$/5 min) followed by 10.00 h (21.40 bees/$m^2$/5 min.). Moderate foraging activity with 15.84 bees/$m^2$/5 min and 14.01 bees/$m^2$/5 min was observed at 08.00 h and 11.00 h, respectively. Less activity was observed at early morning hours and midday hours ranging from 1.60 to 5.17 bees/$m^2$/5 min. The foraging activity of *T. iridipennis* decreased with its minimum at 13.00 h (1.00 bees/ $m^2$/5 min.).

The studies carried out by Shubhakar and Shreedevi (2015) indicated that though the number was very less in case of *H. gutturosus* and *A. florea*, the foraging rate was higher increasing its pollination efficiency and in spite of *T. iridipennis* being high in bitter gourd ecosystem, its pollination efficiency was lesser. They also studied the foraging speed of major bee species on bitter gourd flowers and the results indicated that the maximum time spent by *T. iridipennis* was 89.20 s with meantime of 40.62 s per flower followed by *H. gutturosus* which spent maximum and minimum time of 31.20 and 4.20 s, respectively with mean foraging time of 10.80 s per flower. Among all three major pollinators, *A. florea* spent less time on flowers. The maximum time spent by *A. florea* was 14.26 s with mean foraging time of 9.28 s per flower. This was recorded during the peak foraging hour of all three bee species.

### 2.4 Effect of pollinators on pollination and fruit set in bitter gourd

Mann and Robinson (1950) observed that muskmelon fruit consisted less than 400 seeds. The effective period in which pollen could be deposited on the stigma was no more than a few hours in the morning, and if the temperature was high, the period might be only a few minutes. Single massive deposits of pollen by hand on the stigma were seldom as effective in the setting of fruit as repeated bee visits.

Mann (1953) reported that the per cent fruit set from hand and open pollinations in four tests in muskmelon was respectively, 39 vs. 67; 60 vs. 91; 30 vs. 50 and 48 vs. 78. It was shown further that, fruit set was much more uniform from day to day for open than for hand pollination. Open-pollinated flowers produced larger fruit and more seeds than hand-pollinated flowers.

Taylor (1955) studied the production of muskmelon in 37 fields in Salt River valley of Arizona in relation to proximity to honey bee colonies. In 20 fields with an average of one-half colony per acre within a mile, production was 1.06 melons per plant and 242 crates per acre. In 17 fields with no hives of bees in the "visible vicinity," production was only 0.67 melon per plant and 161 crates per acre. The fields with and without honeybee colonies in the crop vicinity gave 1.10 and 0.70 melons per plant, respectively, which was equivalent to 230 and 160 crates/acre, respectively.

Alex (1957) reported that the isolation of muskmelon plants from pollinating insects and caging of plants with bees have proven that hermaphrodite flowers were incapable of performing self-pollination. The pollen must be transferred from the anthers to the stigma by insects.

Verdieva and Ismailova (1960) recorded 47 to 57 kg squash from plots pollinated by honey bees compared to 25 to 30 kg from plots pollinated by other bees.

Conner (1969) examined that a single bee visit to a pistillate flower often resulted in well-shaped cucumber. At least 10 bee visits were necessary to ensure pollination under all conditions, whereas eight to 12 visits per blossom were needed for yield uniformity in cucumber (Stephen, 1970). Collison (1976) observed that 15 to 20 bee visits were needed to get uniform cucumbers and multiple bee visits increased the average number of seeds, which resulted in better and maximum fruit weight.

Battraglini (1969) reported that fruit set was 61.20 per cent of the total pistillate flowers exposed to bees in comparison with decreased fruit set of only 6.80 per cent, when flowers were bagged in *C. pepo*.

Honey bee pollination increased the average weight and quality of cucumbers both in open and plots caged with honey bees. The yields of muskmelon fruits were higher in plants pollinated by bees, and plants in which bees were excluded set practically no fruits (Kauffeld & Williams, 1972 and Kauffeld *et al.*, 1975).

Experiments in which pumpkin flowers were bagged to exclude bee visits and exposed to different numbers of bee visits showed that the fruit set was 6.5 per cent after one visit and 64.5 per cent after 12 visits per flower. The pumpkin weight and number of seeds also increased with number of visits (Jaycox *et al.*, 1975).

Grewal and Sidhu (1979) recorded least fruit set (25.00 %) in the plots where the summer squash was allowed with one or two bee visits. They also reported that ten bee visits were necessary to get maximum fruit set (47.49 %) followed by five bee visits (40.80 % of fruit set). These results indicated that minimum five bee visits were sufficient for satisfactory fruit set in summer squash. Kauffeld and Nelson (1982) reported that the yield of pickling cucumber was highest in the plots caged with *A. mellifera* than open plots and was lowest in control plots.

There was no fruit set in watermelon plots excluded from insect pollinators. The fruit number and fruit weight were higher in honey bee pollinated crop compared to open pollination (Mohan Rao and Suryanarayana, 1988).

Shikhalia *et al.* (1990) observed that artificial pollination in spine gourd resulted in 87.67 per cent fruit set compared to 25.67 per cent under natural pollination. Fruits took 27 days to reach maturity. Marketable fruits were obtained 12 days after fruit set.

William Rajasekhar (2001) studied the effect of bee pollination in watermelon. He reported that significantly higher fruits per 30 $m^2$ was recorded with two colonies per plot (22.37), followed by one colony per plot (20.75) and the lowest with no colony (18.37). Similar results were also obtained with respect to mean fruit weight, fruit diameter, total soluble sugar per cent and yield.

Nidagundi and Sattagi (2005) noticed that significantly higher length of fruits in bitter gourd (26.10 cm) was obtained with honey bees, as against 13.93 and 13.60 cm fruit length in open pollinated and caged plot without bees, respectively, with a pulp ratio of 0.132 as against 0.09 and 0.07 in open pollinated and caged plot without bees, respectively. Highest fruit weight of 129.21g as against 72.09 and 62.44g in open pollinated and caged plot without bees, respectively and yield of 118.87 kg as against 68.63 and 45.23 kg in open pollinated and caged plots without bees, respectively was observed.

Kuberappa *et al.* (2006) demonstrated that fruit weight (5066.25g), fruit volume (4985.00 ml) and pulp ratio (10.28 %) were maximum in open pollination of pumpkin compared to other modes of pollination. Hand pollination either at 09.00h or 10.00h did not make any significant difference in the per cent fruit set, fruit weight, pulp ratio and seed germination. The number of sound seeds per fruit (258.25) and seed weight (52.65g) were maximum in hand pollination at 09.00h compared to other modes of pollination. Hemanth Kumar (2006) reported that minimum of eight bee visits per flower were necessary in pumpkin to get fruit set, fruit weight, fruit volume and number of sound seeds per fruit.

Yang *et al.* (2007) reported that muskmelon fruits pollinated by honey bees were smaller compared to those by bumble bees, and that the fruits pollinated by bumble bees were with higher soluble solids.

Ramesh (2007) reported that maximum fruit set, fruit weight, fruit volume, fruit length, number of sound seeds/fruit and 100 seed weight was more with eight bee visits per flower in ridge gourd. Whereas, in summer squash maximum fruit weight, fruit volume, number of sound seeds per fruit and seed weight were recorded in open pollinated crop, followed by *A. cerana, A. florea* and *T. iridipennis* pollinated crop (Manjula, 2007).

Fruit set in insect-pollinated (78 %) and hand-pollinated (80 %) flowers did not significantly vary in bitter gourd. Likewise, there was no significant difference in fruit weight, length, diameter and number of seeds between both methods. Flowers that were not visited by pollinators set no fruits (Deyto and Cervancia, 2009). According to Maryl *et al.* (2012) fruit set and yield were pollen limited as all bagged flowers were aborted. Fruit set under natural pollination was very low which revealed the degree of pollen limitation in *M. charantia*. Low fruit set was consistent with observation of high discrimination against pistillate flowers amongst potential pollinators.

No evidence for apomixis or spontaneous self-pollination in the absence of insect visitors was found in muskmelon. Pollen origin had no effect on fruit and seed set (Leonie *et. al.,* 2009).

Rubina (2010) reported that maximum fruit set (94.60 %), fruit weight (1619.09g), fruit volume (1621.88 ml), fruit length (33.46 cm) number of sound seeds per fruit (451.31) and seed weight (5.29g) in cucumber were recorded in open pollinated crop, followed by *A. cerana, A.florea* and *T. iridipennis* pollinated crop.

Srikanth (2012) reported that maximum fruit weight (1.87 kg), fruit volume (2340 ml), fruit length (43.93 cm) number of sound seeds per fruit (423) and seed weight (16.58g) in bottle gourd were recorded in open pollinated plot with attractants compared to crop caged without bees (69.43g) which indicated that pollinators were must for higher fruit set in bottle gourd.

Carr and Davidar (2015) mentioned that levels of pollinator dependency ranged from 0 per cent in tomato to 76 per cent in bitter gourd, and pollinators required for fruit set in brinjal (aubergine), tomato, chilli pepper (Solanaceae), okra (Malvaceae), bitter and snake gourds (Cucurbitaceae) crops. Monoecious and andromonoecious crops were more reliant on pollinators than hermaphrodite crops. Tomato, chilli and okra produced self-compatible hermaphrodite flowers, with higher levels of autogamous fruit set (32-76 %) and significantly lower levels of pollinator dependency (0-37 %), whereas andromonoecious brinjal and monoecious gourds had significantly lower levels of fruit set through autogamy, and higher levels of pollinator dependency. Pollen limitation was not evident in any crop.

### 2.5 Role of pollinators in seed production

Studies on the influence of honey bee visits to tomato (*Lycopersicon esculentum* Mill.) flowers in polyethylene greenhouses (Spangler and Moffett, 1977) showed that *A. mellifera* erratically visited tomato flowers. Flowers of Florida tomatoes that exposed to bee visitation produced significantly more tomatoes by weight (22 %) compared to those flowers that were prevented from bee visits by cheese cloth bags.

Mishra *et al.* (1988) found that *A. cerana indica* F. was the most common pollinating species in *Brassica campestris* L. var. *sarson* and percent pod setting, seeds per pod and proportion of healthy seeds were significantly higher in open pollinated flowers than in net caged and muslin bagged ones.

Aagren (1996) made studies on the population size, pollinator limitation and seed set in the self-incompatible herb *Lythrum salicaria* L. He revealed that there was a positive relationship between population size and seed production per flower and between population size and total seed number per plant.

Dogterom *et al.* (1998) observed that *Bombus vosnesenskii* was an effective pollinator of tomatoes in greenhouses. Bumble bee pollinated flowers produced larger fruits than non-bumble bee pollinated flowers.

Hoffman and Watkins (2000) studied influence of *A. mellifera* and non-*Apis* bees on cross-pollination and seed set of hybrid sunflower (*Helianthus annuus* L.). The results indicated that a combined effect of honeybee and non-*Apis* bee population might result in better pollination of hybrid sunflowers than either population alone.

Honeybees and other insects are known to play an important role in seed setting of *Brassica* crops and their hybrid seed production (Westcott and Nelson, 2001).

A study was conducted to find out the role of honeybees on pollination, seed setting and seed quality of hybrid sunflower. The seed setting percentage and seed yield were significantly increased when the honey bees were supplemented to the open pollination. The yields were drastically reduced when the crop was covered with insect proof net. In addition, increased seedling vigour, germination percentage, field emergence, oil content and quality of seeds were observed with the deployment of honey bees coupled with supplemental hand pollination (Rajasri *et al.*, 2012).

# III MATERIAL AND METHODS

The present investigation on “Role of flower visitors in bitter gourd (*Momordica charantia* L.) pollination and seed production” was carried out during 2014-2016 at the Zonal Agricultural Research Station, Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences, Bengaluru (13° N & 77° 35' E; 930 m above MSL) and in farmers fields near Rajanukunte, Bengaluru rural district located in the south eastern dry zone of Karnataka state. The soil type is lateritic sandy clay. The details of materials used and methodology followed during the present investigation are presented in this chapter.

## General climatic conditions of GKVK

Gandhi Krishi Vignana Kendra (GKVK) campus of the University of Agricultural Sciences, Bengaluru receives an mean annual rainfall ranging from 679.1 to 899.6 mm. Average number of rainy days on the campus were 56 days. The total rainfall received during 2014 and 2015 was 927.1 and 1049.3 mm, respectively and it was evenly distributed in both *kharif* and *rabi* seasons. In 2014, the total rainfall in *kharif* and *rabi* was 351.4 and 458.8 mm, respectively, whereas in 2015 it was 491.6 and 275.4 mm, respectively. January was the coldest month in both 2014 (14.2 ºC ) and 2015 (15.2 ºC ), while April (34.7 ºC ) and March (32.2 ºC ) were the hottest months in the two years, respectively. The relative humidity was low in March (33and 37 %, in 2014 and 2015, respectively) and highest in October (94 %) and November (94 %) in 2014 and 2015, respectively. The average daily duration of bright sunshine hours was high during February to March (9.5 hours) and low in the months of July and August (4.8 hours). The average daily open pan evaporation ranged from 4.8 mm per day (November) to 7.6 mm per day (March). Wind speed ranged from 5.5 km $hr^{-1}$ (December) to 12.2 km $hr^{-1}$ (June).

## 3.1 The crop

All observations on species of pollinators, foraging behavior and their role in fruit set were recorded from three crops of bitter gourd grown in three seasons *viz*., *kharif* -2014, *rabi*-2014 and *summer*-2015. The first crop was planted on 13$^{th}$ July 2014, second on 4$^{th}$November 2014 and the third crop on 20$^{th}$ April 2015. The observations on effect of pollinators on seed production were recorded from two crops grown in *kharif* -2016 and *summer*-2015, where in first crop was planted on 1$^{st}$ July and second crop on 12$^{th}$ February. The variety selected for the first objective was Arka Haritha developed by Indian Institute of Horticultural Research (IIHR), Bengaluru whereas, parental lines (BR-8 male and BG-8 female) of bitter gourd were used for second objective. The latter variety is similar to former in floral biology and duration.

The experimental plot measuring 40 m × 20 m was selected for planting (Plate 1). The transplanting was done with a spacing of 100 cm between the rows and 60 cm between plants. The crop was cultivated by following all recommended package of practices of UAS, Bengaluru except plant protection measures.

### 3.2 Floral biology of bitter gourd

Detailed observations were recorded on the floral biology of bitter gourd *viz*., days taken for full bud development, time of anthesis, ratio between pistillate and staminate flowers, pollen to ovule ratio, time of anther dehiscence, time of pollen viability, time of stigma receptivity, nectar quality and quantity by tagging fixed number of randomly selected flowers/plants. Observations were also recorded on the detailed flower structure, position, longevity of pistillate (female) and staminate (male) flowers and also flowering phenology with respect to seasons and time of the year.

#### 3.2.1 Date of flower bud initiation and days taken for the full bud development

Randomly selected 100 plants were tagged and observed frequently to record developing buds. Once bud initiation started, 100 freshly formed buds were tagged to record the date of their opening and subsequent opening of flowers.

#### 3.2.2 Time of anthesis

The time of flower opening (anthesis) was recorded by tagging sets of 100 randomly selected pistillate and staminate flower buds. The tagged buds were observed at different times of the day (early morning, morning, afternoon, evening and late in the evening) to record the time of anthesis. This procedure was repeated two times in each season to know time interval for anthesis during that particular day (Plate 2).

#### 3.2.3 Ratio between staminate and pistillate flowers

In order to know the ratio between staminate and pistillate flowers, 25 vines were randomly selected in *kharif*-2014, *rabi*-2014 and *summer*-2015 seasons and the observations on number of staminate and pistillate flowers in each vine were recorded every day from the day of first flower opening till the end of flowering season. The data was used to compute the ratio between staminate and pistillate flowers.

#### 3.2.4 Flower structure

Fully opened staminate and pistillate flowers were collected from the field and brought to the laboratory. The flowers were then dissected under a stereo-binocular microscope to study the detailed structure. The structure and arrangement of different whorls, including position of sepals, petals, ovary, number of ovules, arrangement of stamens, structure of anther lobes, *etc*., were recorded. The structure of the flower was studied and recorded in the light of its adaptation for cross pollination. Emphasis was laid on those structures that were useful in attracting pollinators and also to those that actually enhance the chances of pollination and fertilization; photographs of the structures were taken using Leica auto montage.

#### 3.2.5 Pollen-Ovule ratio

Pollen-ovule ratio is the ratio between the number of pollen grains to the number of ovules present in a given flower (Cruden, 1977). After complete dehiscence, the staminate flowers prevented from bee visitation were collected in butter paper bags (n = 25), brought to the laboratory and the total number of pollen grains were counted by



**Plate 1 A & 1 B: General plot view in UAS, Bengaluru**

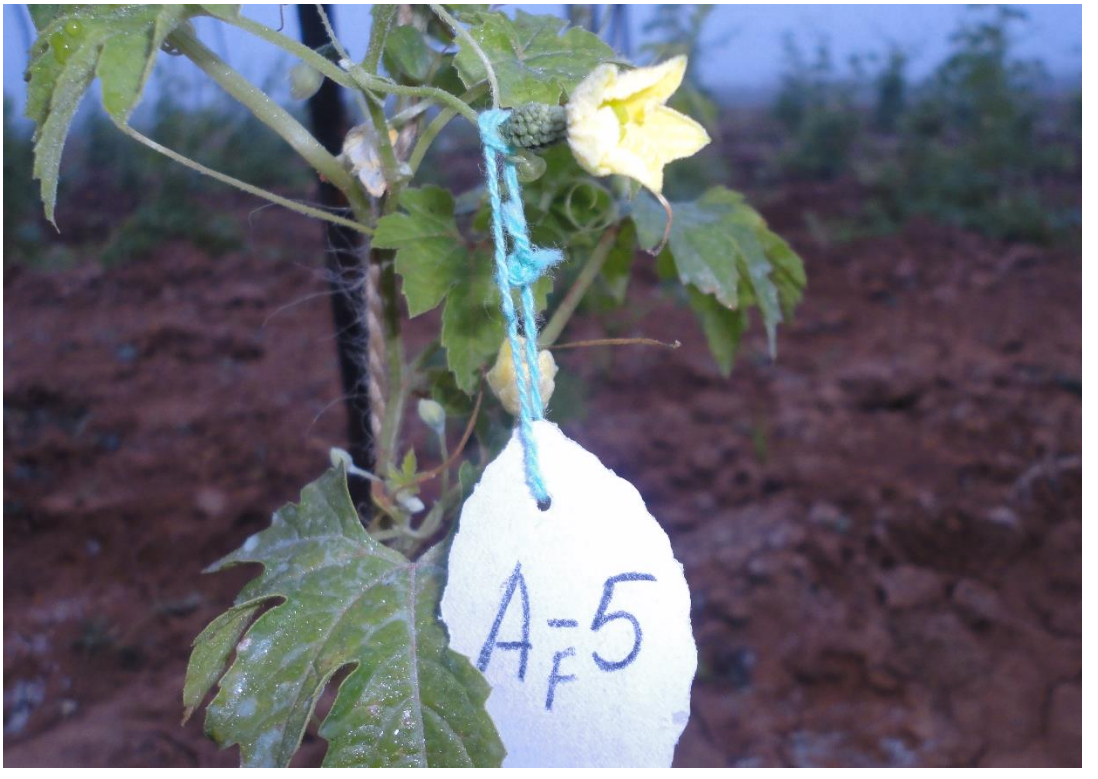

**Plate 2: Tagging of flowers for anthesis**


**Plate 3: Bagged pistillate flowers**

extracting all the pollen into glacial acetic acid (1 ml) in 1 ml plastic vials and number of pollen grains were counted using haemocytometer. The ovule number per ovary was recorded by carefully dissecting the ovary longitudinally. The data was subjected to work out the pollen to ovule ratio.

### 3.2.6 Time of anther dehiscence

Usually, anther dehiscence is the spontaneous opening of anther at maturity to release pollen grains and is coordinated precisely with pollen differentiation, floral development, and flower opening. However, anther dehiscence can occur before flower opening within the bud (Sharma and Green, 1980). Hence, observations were recorded for anther dehiscence at different times of the day by tagging 100 randomly selected staminate flower buds. The flowers were carefully observed in field itself using a hand lens to see whether the anthers were dehisced or not in that particular stage of the bud/flower. This procedure was repeated two times in each season to record the exact time interval for anther dehiscence that occurred on that particular day.

### 3.2.7 Longevity of flowers

Longevity of flowers is the time taken by a particular flower from anthesis till it sets into fruit or till it withers and drops off. Twenty five set of 30 one day staminate and pistillate flowers were tagged in each of the three seasons and were observed daily to record the day of anthesis. The opened flowers were further monitored till they set fruits or dropped off. The study was repeated two times in each season to get the mean longevity of flowers.

### 3.2.8 Pollen viability

Pollen viability test was done to understand the germination capacity of pollen grains and to know the time of maximum germination. The staminate flowers were brought to the laboratory from the field at two hour intervals starting from 06.00 to 18.00h and respective pollen grains transferred on to separate cavity slides having 10 per cent sucrose along with 0.01g boric acid solution and kept for germination (Kearns and Inouye, 1993). Observations were made on the number of pollen grains kept for germination and number of pollen grains germinated (Plate 4). The data was subjected to work out the per cent germination and time of maximum pollen germination.

### 3.2.9 Stigma receptivity

To study the stigma receptivity, two sets (n=30 per set) of pistillate flowers prevented from flower visitors were selected. For every two hours interval, one set was hand pollinated and another set allowed for open pollination and during the remaining hours of the day they were kept bagged. These observations were taken for the whole day from 06.00h to 18.00h. The data was used to work out the per cent stigma receptivity in different times of the day and to record the time of maximum stigma receptivity.

### 3.2.10 Nectar quantification

Total quantity of nectar produced in a flower was measured by closing a set of flowers using paper packets to prevent flower visitors for a known length of time and the nectar was removed completely using a calibrated capillary tube (Plate 5) measured in μL. Nectar from staminate flowers (n=20) and pistillate flowers (n=20) was extracted for every two hour intervals starting from morning 06.00h to evening 18.00h. This was done to establish the relation of nectar production with time of activity of pollinator species, pollen viability and stigma receptivity.

Nectar measurement was also done before and after insect visitation to estimate the quantity of nectar drawn by an individual flower visitor. This data was subjected to compute the number of flowers visited by a single insect to fill its crop.

## 3.3 Flower visitors of bitter gourd

Visual counting, sweep net collection, bee bowl counts, yellow pan trap count, malaise and intercept trap count methods were employed to catch/trap the insects visiting flowers of bitter gourd. The collected/trapped insects were then identified for proper record.

### 3.3.1 Visual scanning/counting

Ad-libitum visual counting of flower visitors was done from 06.00h to 18.00h on a given sampling day with a recording time of 15 minutes and a time gap of five minutes between two observations. The visual counting was repeated eight times in a season for every five days from the date of first flowering where every two sampling days represented 25, 50, 75 and >90 per cent flowering of the crop.

All insects visiting bitter gourd flowers per recording time were counted. Observations were recorded on the species of insects visiting the flowers and number of visits made by each species per recording time at different duration of the day. Sampling day was divided into 12 time intervals of one hour each from 06.00 h to 18.00 h. This was done to record variation in species composition and their abundance, if any, in different times of the day. Most frequent species visiting bitter gourd flowers were recognized during these observations for further studies on foraging behaviour.

### 3.3.2 Sweep net collection of flower visitors

Flower visitors of bitter gourd were also collected at regular intervals and in different times of the day using an insect sweep net (Plate 6). Sweep net samples were collected on different days with different flower densities. Insects collected from sweep net were brought to the laboratory, mounted using insect pins, properly dried and preserved for future identification. Identification of bee species was done using the available keys and the expertise available in the Biosystematics Laboratory, Department of Entomology, UAS, Bengaluru. All voucher specimens have been deposited with the collections of the Department of Entomology, University of Agricultural Sciences, GKVK, Bengaluru.


**Plate 4: Pollen germination test in 10% sucrose solution + 0.01 g boric acid**

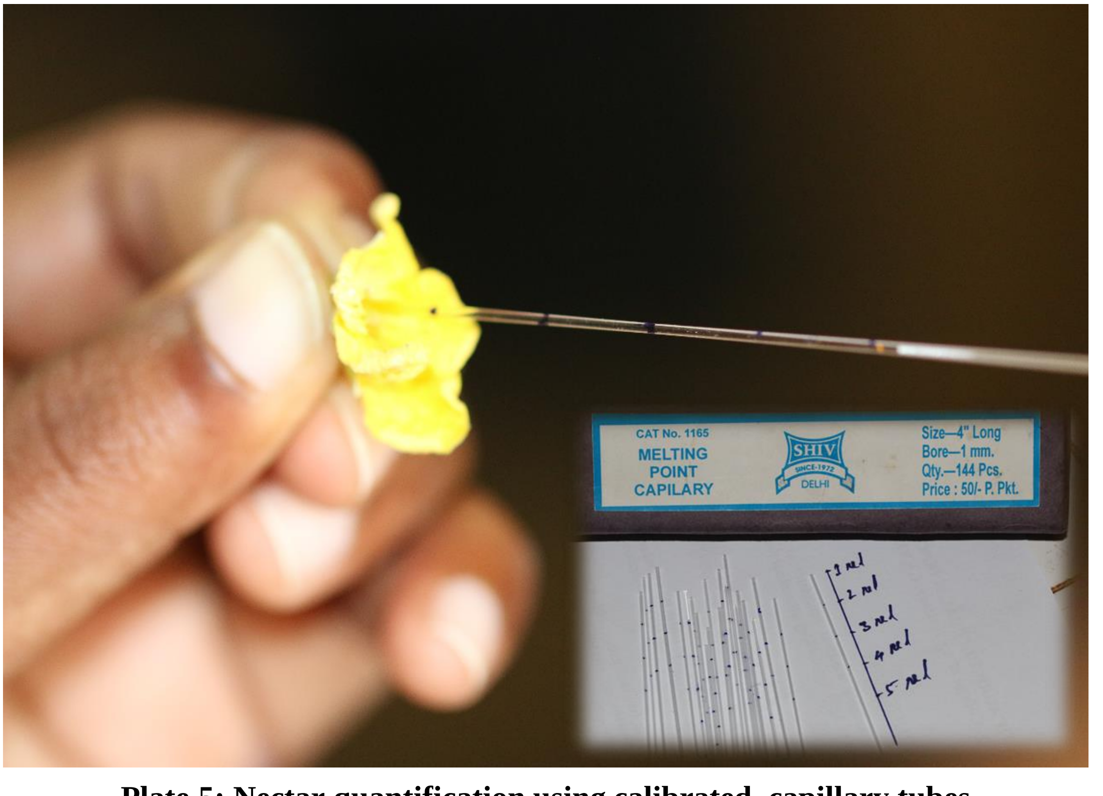


**Plate 5: Nectar quantification using calibrated capillary tubes**

**Plate 6: Sweep net for collection of flower visitors**

**Plate 7: Yellow pan and bee bowls for collection of flower visitors**

### 3.3.3 Bee bowl collection of flower visitors

Bee bowl collection (Plate 7) of flower visitors was done to monitor flowers visitors. Totally five colours of bee bowls (Yellow, White, Blue, Grey and Green) containing water with liquid soap were placed for the whole day on sampling date at five meter apart in field, and this was repeated three times during the cropping period. The flower visitors collected in bee bowls were brought to the laboratory, cleaned, dried and preserved for further use (FAO, 2008)

### 3.3.4 Yellow pan trap

Most insects get attracted to yellow colour, hence, yellow pan traps were used to catch many flying insects (Plate 7). The traps were half filled with water and a few drops of liquid soap added. The traps were randomly placed in the crop field with a distance of at least ten meters. The flower visitors collected in yellow pan trap were brought to the laboratory, washed, dried and preserved for further identification.

### 3.3.5 Malaise and intercept trap

These traps were used for actively flying insects for unbiased sampling. These were used for additional collection of flower visitors active in the field (Plate 8 and 9).

The data collected from the above six methods were used for analyzing the pollinator diversity and density.

### 3.3.6 Diversity of flower visitors

The frequency of visits made by each species was recorded to identify the most abundant species visiting bitter gourd flowers. Pollinator count data was used to compute Shannon-Wiener index of diversity (H) by using the following formula

$$H = \overline{\Sigma}\ pi \times \ln pi$$

Where pi is the proportion of the $i^{th}$ species of pollinator.

The dominant species on any given sampling day was determined by the Berger-Parker dominance index ‘d’, which gave the proportion of the total numbers of individuals in a sample due to the dominant species and was calculated by,

$$d = ni / NT$$

Where ni is the number of individuals of the $i^{th}$ species on sampling date and NT is the total number of individuals in the sample (Southwood, 1988).

### 3.3.7 Correlation studies

The abundance of flower visitors on bitter gourd was correlated with abiotic factors like, maximum and minimum temperature, morning and evening relative humidity, rainfall and sunshine hours that prevailed during bitter gourd flowering.

### 3.4 Foraging behaviour of selected species of pollinators

The foraging behaviour of the most frequent and efficient flower visitor was recorded by closely observing the foraging bees. Selected species of bees for the observations were marked on the pronotum using quick drying paints in order to follow them easily. Observations were recorded on the time of activity of pollinator species, the way each individuals of the species landed on the flower, method it followed for collecting nectar or pollen and the time spent by an individual bee on a flower per visit and also per trip. Observations were also recorded on movement pattern of bees and the number of flowers visited by individual bees.

#### 3.4.1 Time of activity of the pollinator

The time of activity of frequent visitors to bitter gourd flowers was recorded using the data obtained from the visual scanning method.

#### 3.4.2 Number of flowers visited per unit time per trip

Number of flowers visited per unit time was calculated by following individual marked bee (Most frequent visitors, n=30 for each species) from the time it entered the field till the time it escaped from vision or left the field and the number of flowers visited per trip was recorded by following a particular marked bee (Most frequent visitors, n=30 for each species) from the time it entered the field till the time it left the field.

#### 3.4.3 Pollination efficiency

Comparative pollination efficiency of most frequent flower visitors was assessed based on their relative abundance and foraging behaviour parameters such as foraging speed and foraging rate.

Pollen removal efficiency and Pollen efficiency index was calculated by using

$$PRi = \frac{Ri - N}{V - N}$$

Where,

Ri = Mean number of pollen grains removed per flower with a single visit

N= Mean number of pollen grains removed per flower with no visit

V= Mean number of pollens removed per flower with unrestricted visits

$$PEi = \frac{Pi - Z}{\mu - Z}$$

Where,

Pi = Mean number of seeds in fruits that restricted to only one visit by species

Z = Mean number of seeds with no visits

μ = Mean number of seeds with unrestricted visits

**Plate 8: Intercept trap set up for collection of insect pollinators**

**Plate 9: Malaise trap set up for collection of insect pollinators**

### 3.4.4 Movement pattern

Movement pattern is the number and sequence of visits made by particular species of bee to both the sexes of flowers of a crop during a particular trip. In the selected patch (n= 120 vines) of the experimental plot, every flower was tagged serially, irrespective of whether it was a staminate or pistillate flower. Marked bees were followed and the serial number of flowers which they visited was sequentially recorded from the time they entered the patch till the time they left the selected patch. Later these numbers were replaced with the name of respective sexes of flowers and the data was used to work out the movement pattern. Observation was also taken on the distance travelled by a particular species of bee during each trip in the selected plot. Using the data obtained from selected plot, distance travelled per minute was worked out and used to calculate the distance travelled per total foraging trip.

### 3.4.5 Time spent per flower

Time spent per flower by most frequent visitors of bitter gourd flower was done by following marked bees (n=30 flowers) and the time spent from the moment it landed on a flower till it left the flower was also recorded. This was done for both pistillate and staminate flowers.

### 3.4.6 Reward collected

Reward collected was defined as nectar or pollen collection or both by flower visitors. In bitter gourd plants observations on reward collection by flower visitors was recorded by observing a particular species of marked bee from the time of activity started till the activity of bees ceased.

## 3.5 Role of flower visitors in pollination and fruit set

Several experiments including controlled visits by pollinating species, open and hand pollination were conducted to know the effect of pollinator visitation on effective fruit set over other methods. Observations were recorded on number of fruits set, fruit size, weight and number of seeds.

Observations were also recorded on the relation between the number of visits by a pollinator and per cent fruit set, relation between the time of visit and per cent fruit set and also relation between species of flower visitors and per cent fruit set. All the collected data were subjected to statistical analysis.

### 3.5.1 Controlled experiments (Pollinator exclusion study)

Seven sets of randomly selected pistillate flowers were covered using paper packets and allowed for controlled visits by the pollinating species (Plate 3). The number of visits to each set of flowers (n=30) allowed in the experiment were 0, 1, 2, 5, 10, 15 and 20 respectively and observations were recorded on the number of fruits set, size and weight of fruits and seed number. Similar observations were also recorded on additional set of randomly selected flowers (n=30 each) subjected for open and hand pollination.

### 3.5.2 Role of honey bees in green house condition (Pollinator exclusion study)

Four sets of randomly selected 25 flowers were covered individually using paper packets. One set was opened for hand pollination while the other set was allowed only for *A. cerana* pollination (1 colony) in the green house. Flowers of third set were tagged and left for open pollination. Flowers of fourth set were tagged and left for open pollination along with introduction of *A. cerana* colony (Plate 10 and 11). Observations were made on fruit weight and seed number. The data obtained was subjected for analysis.

### 3.5.3 Time of visit and per cent fruit set

Sets of randomly selected pistillate flowers (n=30) were allowed visitation by pollinating species at particular time interval of two hours and were bagged during other times of the day. This experiment was repeated several times starting from 06.00h to 18.00h. The data obtained was used to work out the time of effective pollination for maximum fruit set.

### 3.5.4 Species of flower visitor and per cent fruit set

Sets of randomly selected staminate flowers (n=30) were allowed for visitation by a particular species of bee from the time of flower opening till the time it closed and these flowers were prevented from other bee visits by chasing them away. The data obtained was used to work out the species of visitor and per cent fruit set.

### 3.5.5 Different pollination treatment experiment

Four sets of randomly selected 25 flowers were covered individually using paper packets. One set was opened for hand pollination and the other set was allowed only for *A. cerana* pollination (1 colony contains four frames) in the green house. Flowers of third set were tagged and left for natural pollination. Flowers of fourth set were tagged and left for natural pollination along with introducing an *A. cerana* colony (1 colony contains four frames). Observations were made on fruit weight, seed number, seed weight.

## 3.6 Role of honey bees in seed production of bitter gourd

Controlled experiments were conducted in two seasons, *summer*-2015 and *kharif* - 2016, where first crop was planted on 1st July 2015 and 25th December 2016, respectively to record the effect of pollinator visitation on effective fruit set and seed number (Plate 12 and 13). The lines of bitter gourd plants *i.e.,* male (removal of pistillate flower) and female (removal of staminate flowers) lines were selected and tried with different male: female ratios which was compared with hand pollination as control with an isolation distance of 15m from one plot to another.

$T_1$ – Male: Female (1:1)

$T_2$ – Male: Female (1:2)

$T_3$ – Male: Female (1:4)

$T_4$ – Control (Hand pollination)

**Plate 10: General plot view in Karlapura, Rajanakunte, Bengaluru**

**Plate 11: General plot view of bitter gourd under green house condition in UAS, Bengaluru**

**Plate 12: General plot view of bitter gourd (1:1Ratio) for seed production in UAS, Bengaluru**

**Plate 13: Tagging of fruits for seed collection in different ratios**

### 3.6.1 Germination and seed viability test

One hundred seeds of four replicates were drawn at random from each treatment and the germination test was conducted using between paper (BP) method as per ISTA standards (ISTA, 2010). The rolled towels were incubated in germination chamber maintained at 25 ± 1 ºC and 90 per cent relative humidity. The germinated seedlings were evaluated on 7$^{th}$ day during final count and percentage germination was expressed based on normal seedlings.

Three replications of five grams of seeds from each treatment were weighed up to two decimal places. The seeds were treated with acetone for five minutes and then washed thoroughly with distilled water. The surface sterilized seeds were soaked in 25 ml of distilled water and incubated for 24 hours. Then the steeped water from the soaked seeds were collected and electrical conductivity (dSm-1) of the leachate was measured by using the digital conductivity meter model. After subtracting the EC of the distilled water from the value obtained from the seed leachate, the actual EC due (the leachate) to electrolyte was measured and expressed in $dSm^{-1}$ at 25 ± 1 ºC temperature.

Dehydrogenase activity is also known as tetrazolium reduction ability. The activity of dehydrogenase enzyme is directly correlated with the seed vigour. To test the total dehydrogenase enzyme (TDH) activity**, t**wenty five seeds from each treatment were preconditioned by soaking in water for 24 hours. Seeds coat were removed and soaked in 4 ml of 0.5 per cent Tetrazolium solution. They were incubated at 25 ºC in dark for 12 hours and then washed thoroughly with distilled water. The red colour (Formazan) developed was eluted from the stained embryos by soaking in 5ml of 2 Methoxy ethanol for 24 hours in a screw capped vials until all the seeds discolored . The extract was decanted and the colour intensity was measured in Spectrophotometer (model SL171) at 480 nm with suitable blank (2 Methoxy ethanol). The TDH activity was expressed in terms of optical density value (Perl *et al.*, 1978).

# IV RESULTS AND DISCUSSION

The results of the present investigation on bitter gourd including floral biology, floral traits and flower visitors, foraging behaviour of pollinators and its importance in enhancing fruit set and role of pollinators in seed production are presented and discussed in this chapter in the light of available literature.

## 4.1 Floral biology of bitter gourd

A detailed study on the floral biology of bitter gourd was made which included flower structure, position, longevity, days taken for full bud development, time of anthesis and anther dehiscence, ratio between pistillate and staminate flowers, pollen to ovule ratio, nectar quality and quantity, time of pollen viability and stigma receptivity of staminate and pistillate flowers respectively, by tagging fixed number of randomly selected flowers/plants and also flowering phenology with respect to seasons and time of the year. The findings of these studies and observations are presented and discussed here under.

### 4.1.1 Flowering phenology with respect to seasons or time of the year

The crop started flowering 37 to 43, 38 to 47 and 40 to 46 days after planting with a mean of 40.03 ± 1.94, 43.37 ± 2.13 and 42.60 ± 1.92 days in *kharif*-2014, *rabi*-2014 and *summer*-2015, respectively (Table 1). Fifty per cent flowering was observed at 60-65 days after planting in all the three seasons. The flowering period during *kharif*-2014 was between 23$^{rd}$ August-2014 and 21$^{st}$ October-2014, in *rabi*-2014, it was between 15$^{th}$ December-2014 and 12$^{th}$ February-2015 whereas in *summer*-2015 it was between 30$^{th}$ May-2015 and 28$^{th}$ July-2015.

**Table 1: Date of first flower opening of bitter gourd crop during *kharif*-2014, *rabi*-2014 and *summer*-2015 (n=30 plants)**

| Seasons | Date of sowing | No. of days required (Mean ± SD) |
|---|---|---|
| ***Kharif*-2014** | 13-Jul-14 | 40.03±1.94 |
| ***Rabi*-2014** | 4-Nov-14 | 43.37±2.13 |
| ***Summer*-2015** | 20-Apr-15 | 42.60±1.92 |

The total flowering period in all three seasons ranged from 58 to 60 days. There were two peaks during the flowering period in all the three seasons. First peak was observed on 30$^{th}$, 32$^{nd}$ and 24$^{th}$ day, respectively from the day after first flowering, while the second peak was at 45$^{th}$, 46$^{th}$ and 42$^{nd}$ day, respectively from the day after first flowering (Fig. 1, 2 and 3). Both staminate and pistillate flowers opened synchronously. Flowers of the both sexes had a long period of overlap in flowering. Palada and Chang (2003) reported that flowers of bitter gourd appeared 30-55 days after sowing, as in the current study. The present investigations are in accordance with the studies made by Pal *et al.* (1976) on floral biology of *M. charantia* and they revealed that bitter gourd vines started flowering 40 days after sowing and blooming period varied from 68 to 76 days.

The plant is protandrous in nature. In all the seasons, the plants started producing staminate flowers six to seven days earlier than the pistillate flowers, as observed by Pal *et al.* (1972), Deyto and Cervancia (2009) and Mary *et al.* (2012). The plant may get benefited by delayed production of pistillate flower, which inturn would help the pollinators to become active. Since the plant started producing staminate flowers six to seven days before pistillate flowers, the pistillate flowers get greater density and diversity of pollen. This will help the plant to get more pollination to produce maximum fruits.

### 4.1.2 Detailed flower structure

The bitter gourd plant is monoecious (pistillate and staminate flowers borne separately on the same plant but at different internodes), a fast-growing trailing or climbing vine with thin stems and tendrils. It bears simple, alternate leaves with three to seven deeply separated lobes which measures about 2 cm from each node. Each plant produces several solitary staminate and few numbers of pistillate flowers in synchronous manner. Both staminate and pistillate flowers were yellow with similar corolla shape and petal arrangement. The staminate flowers were borne singly in each leaf axils of the vine *i.e.*, between leaf stalk and growing stem; whereas pistillate flowers produced on 10 to $15^{th}$ nodes along with two leaves on longer stalks that arose from axillary points.

The staminate flowers were solitary, pale yellow and sweet-scented during anthesis and incomplete, imperfect, regular, actinomorphic, apopetalous supported on long thinner stalks. The perianth consisting of corolla was accompanied by calyx below. Corolla tube consisted of five yellow coloured petals which were fused at the base beyond the staminal column then separated and spread distally, whereas a cup shaped greenish calyx separated into five very thin sepals distally surrounding the corolla base. The staminate flowers had five stamens which appeared to be three, since two sets had two fused anthers, producing two compound stamens and one simple stamen. The anthers were covered with orange-yellowish coloured pollen grains. Pollen grains shed by longitudinal splitting of the anther. The pollen grains were round in shape and each pollen grain measured 0.060mm in diameter with 3 distinct germpores. Below the thick filaments, there were tiny openings that lead to the nectar gland (Plate 14). In male (staminate) flowers, the nectar guides were more visible in the radial edges and inside the hypanthium; whereas in female flowers, the nectar guides are more visible in veins of the petals and stigma (Lenzi *et al.*, 2005). Similar findings were also reported by Pal *et al.* (1976) who observed that pollen grains (Size 42.69 to 46.95µ within varieties of bitter gourd) round in shape with three distinct germpores. Shikhalia *et al.* (1990) also observed that the pollen grain of spine gourd (*M. dioica*) was round and yellow with three germpores. The similarity of germpores may be due to both spine gourd and bitter gourd belong to the same genus.

The pistillate flowers were borne on a long stalk, consisting of a similar perianth as in the case of staminate flowers. It consists of an inferior ovary (epigynous) and a three-lobed, wet green stigma that is attached to a columnar, hollow style originating

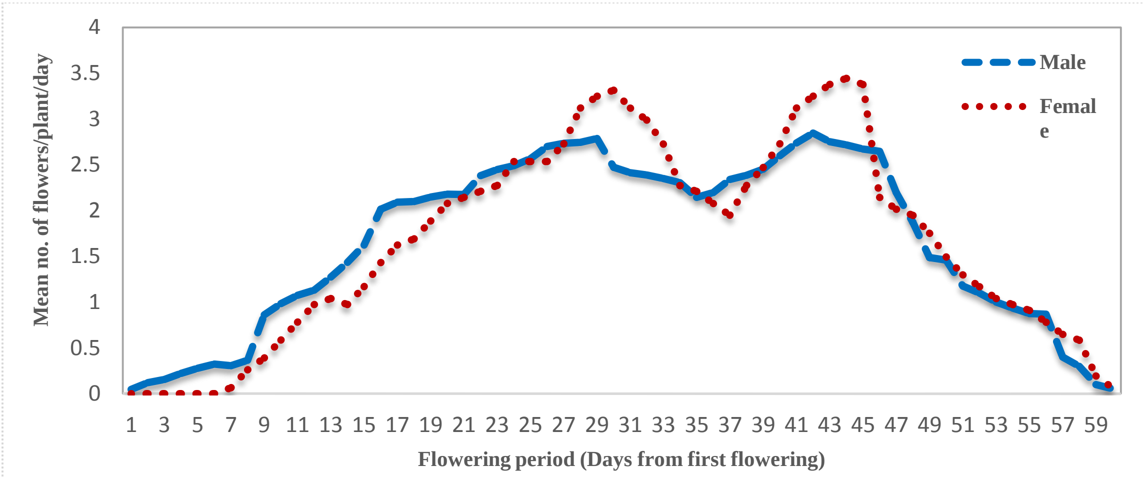


**Fig. 1: Flowering phenology of bitter gourd in *kharif* -2014 season (n=25)**

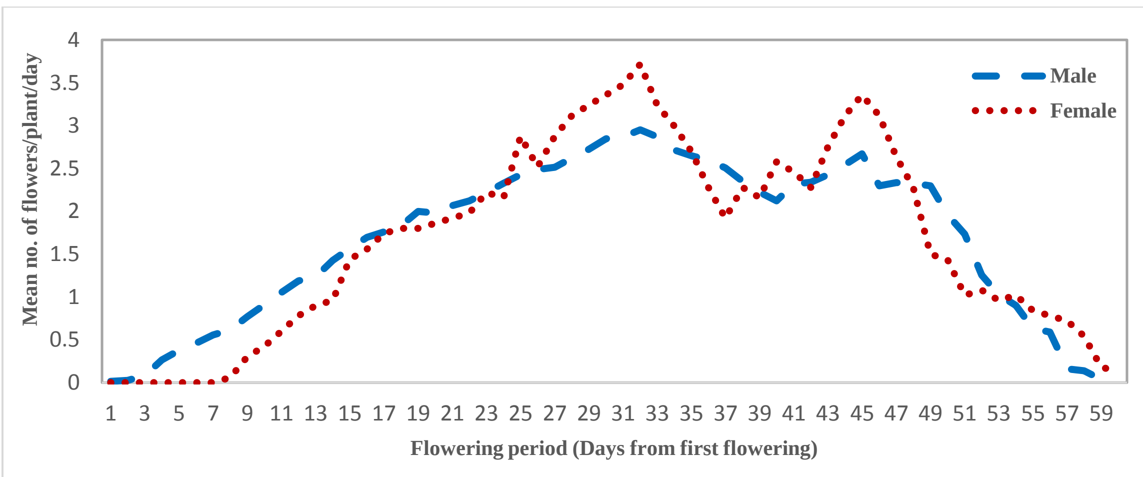


**Fig. 2: Flowering phenology of bitter gourd in *rabi*-2014 season (n=25)**

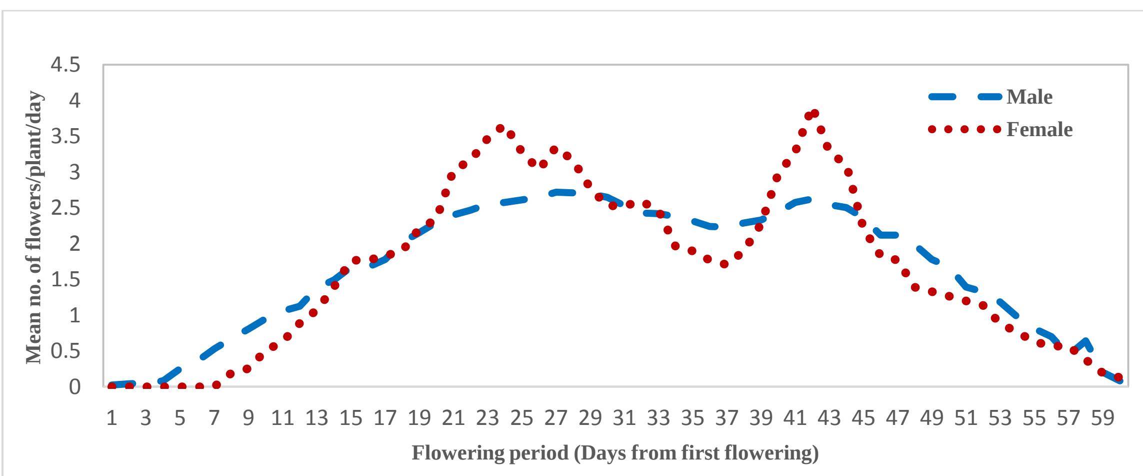


**Fig. 3: Flowering phenology of bitter gourd in *summer*-2015 season (n=25)**


**Plate 14 : Structure of staminate flowers**

from ovary (Plate 15). The female flowers were similar to male flowers but smaller in size and their calyx was reduced. They had a stronger scent than the male flowers. Similar description was given by Pillai *et al.* (1978).

The ovary contained three fused carpels (syncarpous) which is typical for many cucurbits, each with 16 to 20 ovules, surrounded by an ovary wall and the average number of ovules in an ovary, varied from 48 to 60. The present results are in conformity with the findings of Pillai *et al.* (1978) who observed that the number of ovules in an ovary was upto 60 but the average was 40. A negligible percentage (less than 1%) of hermaphrodite flowers were also observed in the bitter gourd plant (Plate 16).

### 4.1.3 Time of anthesis and anther dehiscence

The flowering began early in the morning where staminate flowers started opening from 07.01-08.00 h, 02.46-04.00 h and 05.31-07.15 h in *kharif*-2014, *rabi*-2014 and *summer*-2015 seasons, respectively; whereas pistillate flowers started opening from 05.31-05.45h, 02.01-03.15h and 05.01-06.15h in *kharif*-2014, *rabi*-2014 and *summer*-2015 seasons, respectively.

The maximum anthesis in staminate flowers across three seasons was observed between 07.01-07.45 h (88 %), 03.01-03.30 h (86 %) and 06.01-06.30 h (77 %), respectively, whereas in case of pistillate flowers it was observed between 06.01-06.30h (86 %), 02.01-2.30 h (94 %) and 05.01-05.45 h (80 %), respectively (Table 2 and Fig. 4).

Anthesis of pistillate flowers commenced earlier in the morning during *rabi*-2014 season at around 2.00am; whereas in *kharif*-2014 and *summer*-2015 seasons opening was delayed by two hours (around 5.30am and 5.00am, respectively) and this was followed by opening of staminate flowers which delayed 1 hour after opening of female flowers. Flowers remained open only for a single day in bitter gourd. Later in the evening from 06.00h onwards staminate flowers started closing and all of them dropped on the same day, whereas pistillate flowers started closing after 7.00h onwards but the closed flower remained attached to the fruits for a few days (Table 2). On the second day after anthesis, the flowers were hanging down, dried up completely on the fifth day (Deyto and Cervancia, 2009), as in current study. Similarly, Melendez-Ramirez *et al*. (2002) recorded that the flowers are short lived, begin to open with rising sun and remain open only for a single day. If they not pollinated during that time, the flowers abort and drop from the vine

The present results on anthesis in bitter gourd support the findings of Pal *et al.* (1976) who revealed that anthesis started at 04.00h and continued till 07.30h. The present results are also in agreement with the findings of Deyto and Cervancia (2009) who observed the flower opening at 03.00h and were fully opened at 5.30 -12.00h. The above results suggest that the time of anthesis in bitter gourd occurs anywhere between 02.00h-08.00h across all seasons. The anthesis of bitter gourd appears to be depending on temperature and humidity. When the temperature is low, with high humidity, or the day is

**Table 2: Time of anthesis of bitter gourd during *kharif*-2014, *rabi*-2014 and *summer*-2015 (n=100 flowers)**

| Time of the day (AM) | *Kharif*-2014 | | *Rabi*-2014 | | *Summer*-2015 | |
|---|---|---|---|---|---|---|
| | Mean No. of staminate flowers opened | Mean No. of pistillate flowers opened | Mean No. of staminate flowers opened | Mean No. of pistillate flowers opened | Mean No. of staminate flowers opened | Mean No. of pistillate flowers opened |
| **2:00 -2:15** | 0 | 0 | 0 | 57.25 | 0 | 0 |
| **2:16-2:30** | 0 | 0 | 0 | 23.5 | 0 | 0 |
| **2:31 -2:45** | 0 | 0 | 0 | 12.25 | 0 | 0 |
| **2:46-3:00** | 0 | 0 | 7.25 | 6.25 | 0 | 0 |
| **3:01 -3:15** | 0 | 0 | 43 | 0.75 | 0 | 0 |
| **3:16 -3:30** | 0 | 0 | 26.75 | 0 | 0 | 0 |
| **3:31-3:45** | 0 | 0 | 16.75 | 0 | 0 | 0 |
| **3:46-4:00** | 0 | 0 | 6.25 | 0 | 0 | 0 |
| **4:01-4:15** | 0 | 0 | 0 | 0 | 0 | 0 |
| **4:16-4:30** | 0 | 0 | 0 | 0 | 0 | 0 |
| **4:31-4:45** | 0 | 0 | 0 | 0 | 0 | 0 |
| **4:46-5:00** | 0 | 0 | 0 | 0 | 0 | 4.25 |
| **5:00-5:15** | 0 | 0 | 0 | 0 | 0 | 18.75 |
| **5:16-5:45** | 0 | 0 | 0 | 0 | 0 | 49 |
| **5:46-6:00** | 0 | 10.75 | 0 | 0 | 5.75 | 19 |
| **6:01-6:15** | 0 | 50 | 0 | 0 | 45.75 | 9 |
| **6:16-6:30** | 0 | 30.5 | 0 | 0 | 23.75 | 0 |
| **6:31-6:45** | 0 | 8.75 | 0 | 0 | 13.25 | 0 |
| **6:46-7:00** | 0 | 0 | 0 | 0 | 7.75 | 0 |
| **7:01-7:15** | 36.00 | 0 | 0 | 0 | 3.75 | 0 |
| **7:16-7:30** | 25.25 | 0 | 0 | 0 | 0 | 0 |
| **7:31-7:45** | 28.25 | 0 | 0 | 0 | 0 | 0 |
| **7:46-8:00** | 10.25 | 0 | 0 | 0 | 0 | 0 |
| **8:01-8:15** | 0 | 0 | 0 | 0 | 0 | 0 |

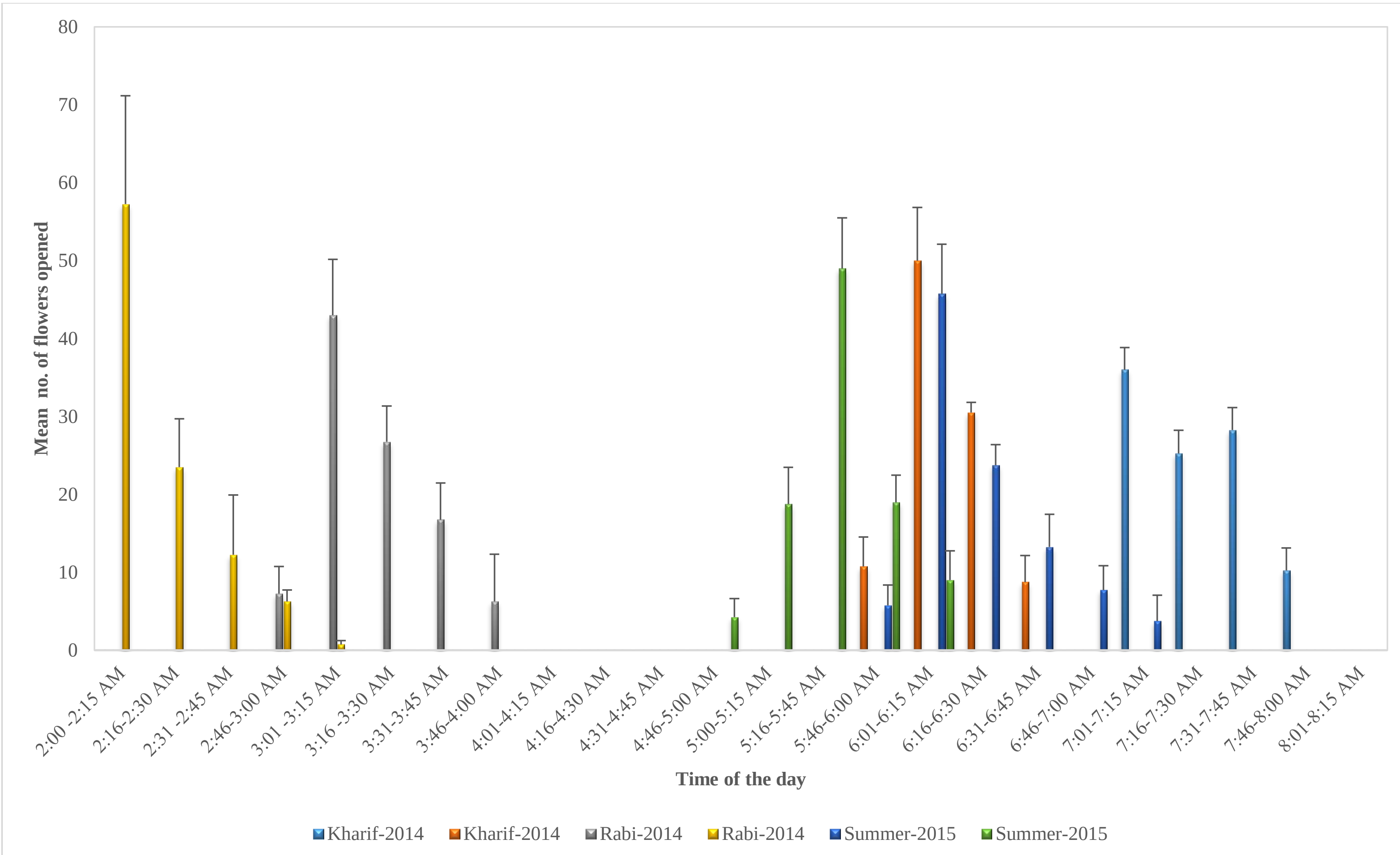


**Fig. 4: Time of anthesis of bitter gourd in *kharif*-2014, *rabi*-2014 and *summer*-2015 (n=4 days)**

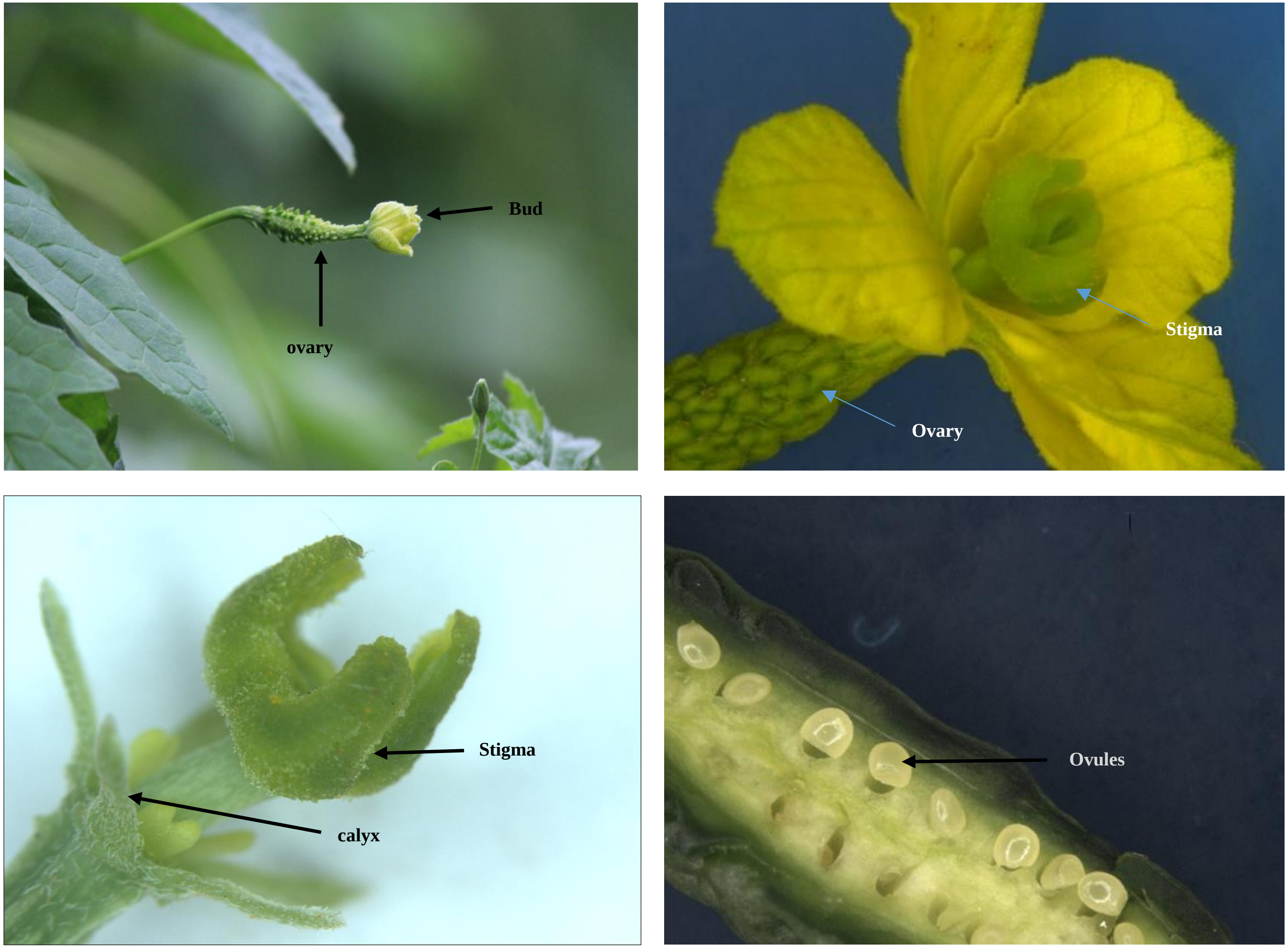


**Plate 15: Structure of pistillate flowers**

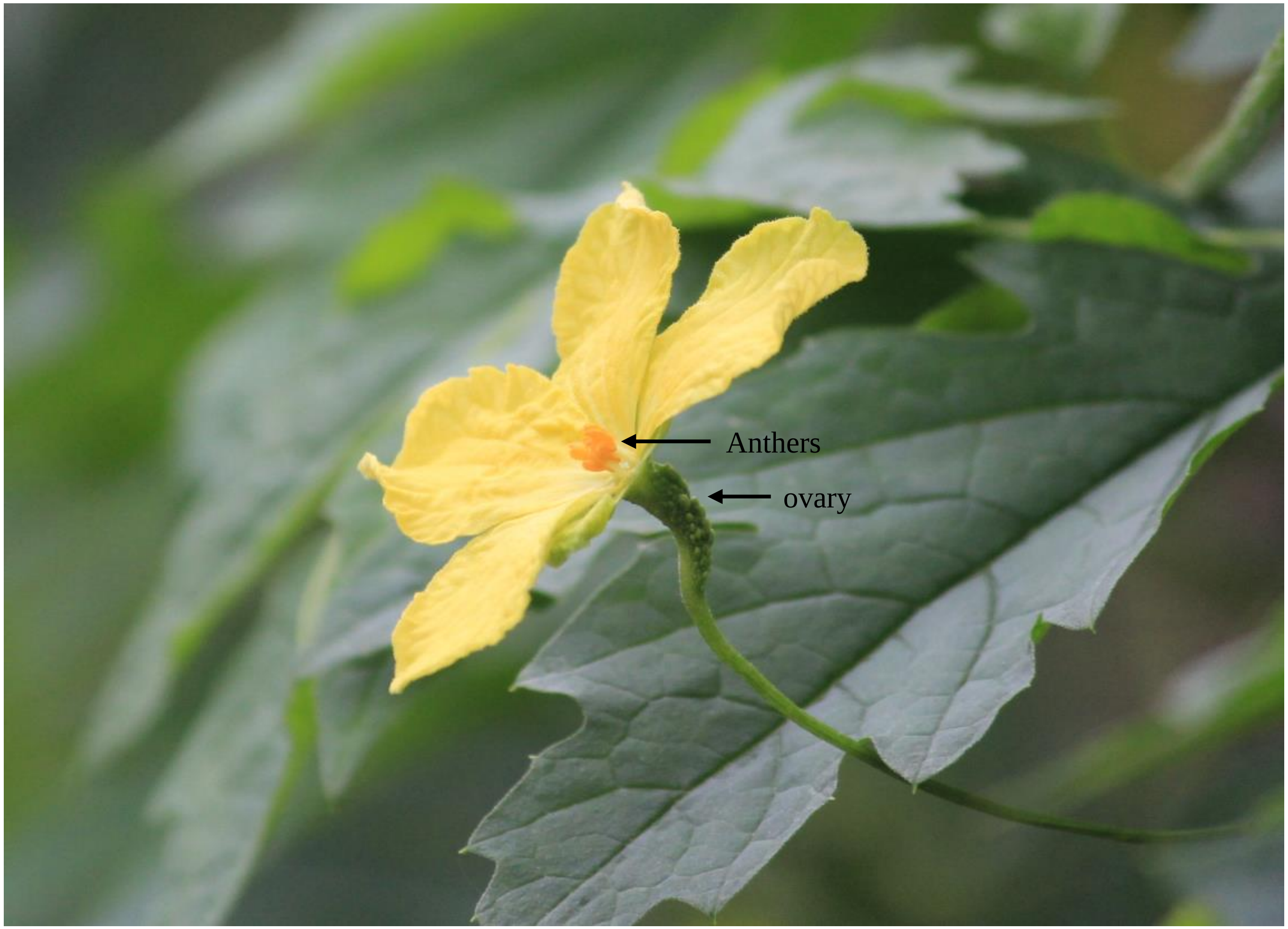


**Plate 16: Hermaphrodite flowers in bitter gourd**

cloudy, opening is delayed and the flower closes permanently in the afternoon of the same day (McGregor and Todd, 1952).

Anther dehiscence in all the three seasons was observed immediately after anthesis of staminate flowers. The anther dehiscence occurred between 07.00 to 8.15 h, 02.46 to 04.00 h and 04.46 to 06.15 h in *kharif*-2014, *rabi*-2014 and *summer*-2015 seasons respectively. The maximum anther dehiscence in staminate flowers in all three seasons was observed between 07.15 to 07.45 h (69 %), 03.15 to 03.45 h (76 %) and 05.30 to 06.00 h (69 %), respectively (Table 3). The present findings are in agreement with Ramesh (2007), Manjula (2007), Rubina (2010) and Srikanth (2012) who opined that anther dehiscence occurred along with the opening of flowers in ridge gourd, summer squash, cucumber and bottle gourd, respectively. In contrast, Pal *et al.* (1976) observed that the dehiscence of anthers happened longitudinally between 6.10 A.M. and 8.55 A.M. In spine gourd, Shikhalia *et al.* (1990) recorded anther dehiscence between 18.00 h and 19.00 h with a peak at 18.40 h.

### 4.1.4 Bud development time and longevity of flowers

The staminate and pistillate buds took an average of 18.87± 0.97 (17-20) days and 6.46 ± 1.28 (4-8) days, respectively in *kharif*-2014; 18.23 ± 1.17 (16-20) days and 5.07 ± 1.26 (3-7) days, respectively in *rabi*-2014 and 19.90 ± 1.92 (17-22) days and 5.23 ± 1.07 (4-7) days, respectively in *summer*-2015 (Table 4). Shikhalia *et al.* (1990) observed that pistillate and staminate buds took 9 and 11 days respectively, to reach anthesis in spine gourd.

### 4.1.5 Ratio between staminate and pistillate flowers

The ratio between staminate and pistillate flowers was 18.69 ± 1.99: 1, 20.13 ± 3.06:1 and 19.94 ± 2.24**:** 1 in *kharif*-2014, *rabi*-2014 and *summer*-2015 seasons, respectively. While in a single plant, ratio of staminate and pistillate flowers ranged between 15.59:1 to 22.40:1, 14.66:1 to 25.68:1 and 14.47:1 to 23.67:1 in *kharif*-2014, *rabi*-2014 and *summer*-2015 seasons, respectively (Table 5).

The staminate to pistillate flower number was very high *i.e.,* the mean number of staminate and pistillate flowers were 1167.08 ± 45.60, 1104.20 ± 46.05 & 1151.12 ± 29.21 and 62.96 ± 5.48, 55.48 ± 7.16 & 58.40 ± 6.61, respectively in *kharif*-2014, *rabi*-2014 & *summer*-2015 with a male to female ratio of 18:1 in *kharif*-2014, 20:1 in *rabi*-2014 and 19:1 in *summer*-2015 (Table 5). The staminate to pistillate flower ratio in bitter gourd was 13:1, 19:1 and 25:1 (Mary *et al.,* 2012; Deyto and Cervancia, 2009 and Palada and Chang, 2003 respectively), as in current study. In contrast, Anusree *et al*. (2015) reported that bitter gourd produced maximum staminate flowers at an average of about 98 % and roughly 2% of pistillate flowers are available for possible fruit set. The high male to female ratio resulting in the production of sufficient amount of pollen probably helps for effective pollination.

**Table 3: Time of anther dehiscence of bitter gourd during *kharif*-2014, *rabi*-2014 and *summer*-2015 (n=100 flowers)**

| Time of the day (AM) | *Kharif*-2014 | *Rabi*-2014 | *Summer*-2015 |
|---|---|---|---|
| | No. of flowers dehisced | No. of flowers dehisced | No. of flowers dehisced |
| 2:00 -2:15 | 0 | 0 | 0 |
| 2:16-2:30 | 0 | 0 | 0 |
| 2:31 -2:45 | 0 | 0 | 0 |
| 2:46-3:00 | 0 | 1 | 0 |
| 3:01-3:15 | 0 | 14 | 0 |
| 3:16-3:30 | 0 | 52 | 0 |
| 3:31-3:45 | 0 | 24 | 0 |
| 3:46-4:00 | 0 | 9 | 0 |
| 4:01-4:15 | 0 | 0 | 0 |
| 4:16-4:30 | 0 | 0 | 0 |
| 4:31-4:45 | 0 | 0 | 0 |
| 4:46-5:00 | 0 | 0 | 0 |
| 5:01-5:15 | 0 | 0 | 4 |
| 5:16-5:30 | 0 | 0 | 13 |
| 5:31-5:45 | 0 | 0 | 40 |
| 5:46-6:00 | 0 | 0 | 29 |
| 6:01-6:15 | 0 | 0 | 17 |
| 6:16-6:30 | 0 | 0 | 0 |
| 6:31-6:45 | 0 | 0 | 0 |
| 6:46-7:00 | 0 | 0 | 0 |
| 7:01-7:15 | 13 | 0 | 0 |
| 7:16-7:30 | 41 | 0 | 0 |
| 7:31-7:45 | 28 | 0 | 0 |
| 7:46-8:00 | 12 | 0 | 0 |
| 8:01-8:15 | 6 | 0 | 0 |
| 8:16-8:30 | 0 | 0 | 0 |

**Table 4: Bud developmental time and longevity period of bitter gourd during *kharif*-2014, *rabi*-2014 and *summer*-2015 (n=30 flowers)**

| Seasons | No. of days required | | | |
|---|---|---|---|---|
| | Staminate flower (Mean ± SD) | Longevity period | Pistillate flower (Mean ± SD) | Longevity period |
| ***Kharif*-2014** | 18.87 ±0.97 | 1 | 6.46±1.28 | 1 |
| ***Rabi*-2014** | 18.23±1.17 | 1 | 5.07±1.26 | 1 |
| ***Summer*-2015** | 19.90±1.92 | 1 | 5.23±1.07 | 1 |

**Table 5: Ratio between staminate and pistillate flowers (S: P) in bitter gourd during *kharif*-2014, *rabi*-2014 and *summer*-2015 season (n=30 veins)**

| Plant No. | ***Kharif*-2014** No. of staminate flowers produced/pl. over 60 days | No. of pistillate flowers produced/pl. over 60 days | Ratio (S: P) | ***Rabi*-2014** No. of staminate flowers produced/pl. over 60 days | No. of pistillate flowers produced/pl. over 60 days | Ratio (S:P) | ***Summer*-2015** No. of staminate flowers produced/pl. over 60 days | No. of pistillate flowers produced/pl. over 60 days | Ratio (S: P) |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 1126 | 66 | 17.06:1 | 1019 | 65 | 15.68 | 1188 | 69 | 17.22:1 |
| **2** | 1142 | 63 | 18.13:1 | 1046 | 61 | 17.15 | 1162 | 62 | 18.74:1 |
| **3** | 1107 | 71 | 15.59:1 | 1059 | 71 | 14.92 | 1144 | 59 | 19.39:1 |
| **4** | 1114 | 73 | 15.26:1 | 1026 | 70 | 14.66 | 1119 | 66 | 16.95:1 |
| **5** | 1126 | 66 | 17.06:1 | 1094 | 64 | 17.09 | 1097 | 57 | 19.25:1 |
| **6** | 1100 | 60 | 18.33:1 | 1044 | 56 | 18.64 | 1121 | 62 | 18.08:1 |
| **7** | 1142 | 61 | 18.72:1 | 1060 | 56 | 18.93 | 1115 | 65 | 17.15:1 |
| **8** | 1310 | 66 | 19.85:1 | 1148 | 65 | 17.66 | 1165 | 56 | 20.80:1 |
| **9** | 1185 | 69 | 17.17:1 | 1090 | 59 | 18.47 | 1145 | 55 | 20.82:1 |
| **10** | 1124 | 67 | 16.78:1 | 1074 | 56 | 19.18 | 1179 | 52 | 22.67:1 |
| **11** | 1158 | 67 | 17.28:1 | 1134 | 58 | 19.55 | 1205 | 63 | 19.13:1 |
| **12** | 1143 | 71 | 16.10:1 | 1073 | 57 | 18.82 | 1143 | 62 | 18.44:1 |
| **13** | 1165 | 59 | 19.75:1 | 1081 | 45 | 24.02 | 1156 | 53 | 21.81:1 |
| **14** | 1212 | 60 | 20.20:1 | 1141 | 54 | 21.13 | 1162 | 53 | 21.92:1 |
| **15** | 1225 | 56 | 21.88:1 | 1193 | 49 | 24.35 | 1189 | 54 | 22.02:1 |
| **16** | 1167 | 70 | 16.67:1 | 1109 | 56 | 19.80 | 1100 | 76 | 14.47:1 |
| **17** | 1165 | 61 | 19.10:1 | 1119 | 52 | 21.52 | 1131 | 50 | 22.62:1 |
| **18** | 1159 | 63 | 18.40:1 | 1118 | 54 | 20.70 | 1158 | 60 | 19.30:1 |
| **19** | 1200 | 64 | 18.75:1 | 1121 | 53 | 21.15 | 1191 | 64 | 18.61:1 |
| **20** | 1224 | 56 | 21.86:1 | 1170 | 52 | 22.50 | 1160 | 53 | 21.89:1 |
| **21** | 1155 | 58 | 19.91:1 | 1150 | 49 | 23.47 | 1143 | 50 | 22.86:1 |
| **22** | 1185 | 60 | 19.75:1 | 1116 | 52 | 21.46 | 1136 | 48 | 23.67:1 |
| **23** | 1188 | 58 | 20.48:1 | 1130 | 52 | 21.73 | 1145 | 55 | 20.82:1 |
| **24** | 1187 | 53 | 22.40:1 | 1130 | 44 | 25.68 | 1131 | 59 | 19.17:1 |
| **25** | 1168 | 56 | 20.86:1 | 1160 | 46 | 25.22 | 1193 | 57 | 20.93:1 |
| **Mean±SD** | **1167.08±45.60** | **62.96±5.48** | **18.69±1.99** | **1104.20±46.05** | **55.84±7.16** | **20.14±3.07** | **1151.12±29.21** | **58.40±6.61** | **19.95±2.25** |
| **Overall Ratio** | **18: 1** | | | **20: 1** | | | **19: 1** | | |

### 4.1.6 Pollen to ovule ratio

The number of pollen grains per staminate flower ranged from 9052 to 11922 with a mean of 10133.48 ± 866.56 and the number of ovules per pistillate flower ranged from 56 to 60 with a mean of 57.48 ± 1.07 (n=25). Pollen grains per ovule per flower ranged between 157.55 to 205.55 and the mean pollen to ovule ratio was found to be 175.27 ± 15.56:1 (Table 6).

Higher ratio of flowers recorded in the present study lead to look at the quantity of pollen produced by staminate flowers, pollen-ovule ratio and also their viability. In the present study, the pollen to ovule ratio was less, the higher ratio between staminate to pistillate flowers increased the overall ratio of pollen-ovules in a plant *i.e.*, ranged from 3161.87 to 3528.18 pollen grains to ovule. Umashankar and Ganeshaiah (1980) have shown that, semi domesticated crop species produce far less quantities of pollen, as pollination is assured, compared to their wild counter parts. In this study, gourd crop suits the report by Umashankar and Ganeshaiah (1980) when we look into individual flower level, but not at plant level because of higher number of male flowers per plant.

### 4.1.7 Pollen viability and stigma receptivity

The pollen viability started from 06.00h onwards and continued upto 18.00h and the maximum pollen viability was observed between 10.00-12.00h of the day in all three seasons *viz.*, *kharif*-2014, *rabi*-2014 and *summer*-2015 with a maximum germination percentage of 96.12, 77.44 and 90.74 between 10.00-12.00h, respectively (Table 7 and Fig. 5, 6 and 7).

The stigma was receptive between 06.00 to 16.00h in all the three seasons. The stigma, receptivity (% fruit set) upon open and hand pollination ranged from 10.00 to 96.67 per cent and 3.33 to 93.33 per cent respectively, in *kharif* -2014 season. In *rabi*-2014 season ranged from 6.67 to 86.67 per cent and 6.67 to 90.00 per cent, respectively. Whereas in *summer*-2015 season it was 80.00 per cent and 86.67 per cent, respectively. The maximum stigma receptivity in open and hand pollination was recorded between 10.00 to 12.00h with a fruit set of 93.33 and 96.67 per cent, respectively during *kharif* -2014 season, 90.00 and 86.67 per cent, respectively in *rabi*-2014 season and while it was 80.00 and 86.67 per cent, respectively in *summer*-2015 season (Table 8). Pollen viability and stigma receptivity coincided with peak activity of pollinators (*A. cerana* and *A. florea*) (Fig. 5, 6 and 7).

According to Deshpande *et al.* (1980) and Shikhalia *et al.* (1990), the stigma was receptive from 12 hour before to 12 hour after anthesis, with a peak at the time of anthesis in snake gourd and bitter gourd, respectively. Pal *et al.* (1976) also observed stigma receptivity to be maximum at the time of anthesis, beginning from 8 hours before anthesis and continued upto 12 hours after anthesis. In muskmelon, the effective period in which this pollen can be deposited on the stigma was not more than a few hours in the morning, and if the temperature is high, the period may be only for a few minutes as observed by Mann and Robinson (1950). This raises a question as to, why there is so much time gap between anther dehiscence and stigma receptivity? The possible answer might be that the pollen remains viable for a longer period of time so that pistillate

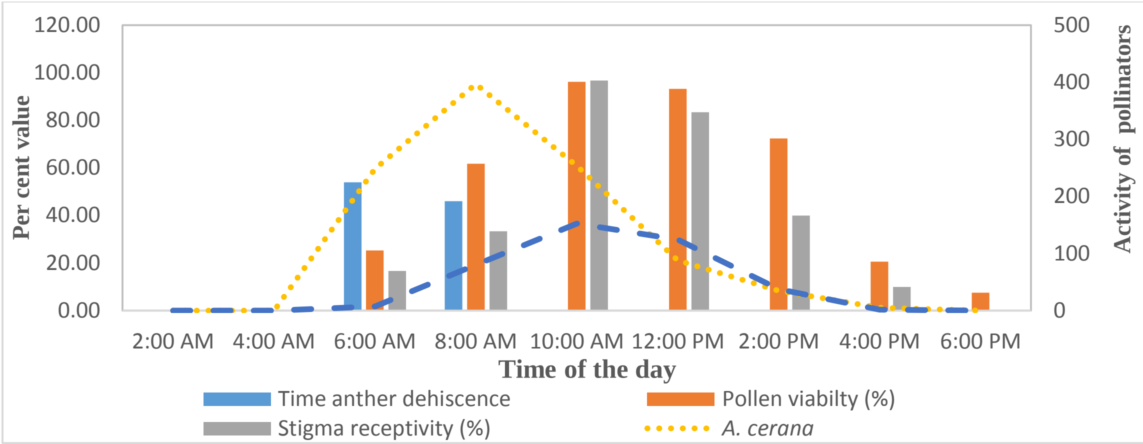


**Fig. 5: Comparison between time of anther dehiscence, pollen viability, stigma receptivity and activity of pollinators in *kharif*-2014 season**

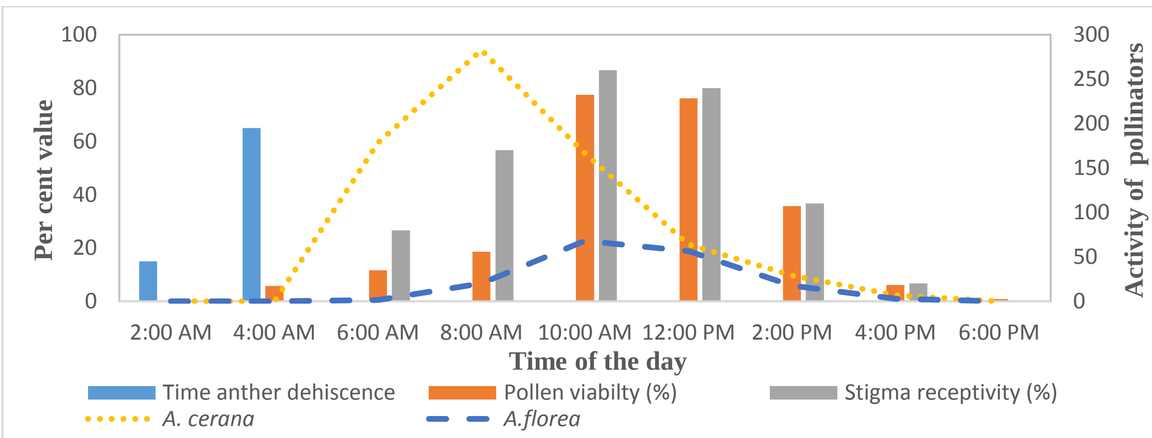


**Fig. 6: Comparison between time of anther dehiscence, pollen viability, stigma receptivity and activity of pollinators in rabi-2014 season**

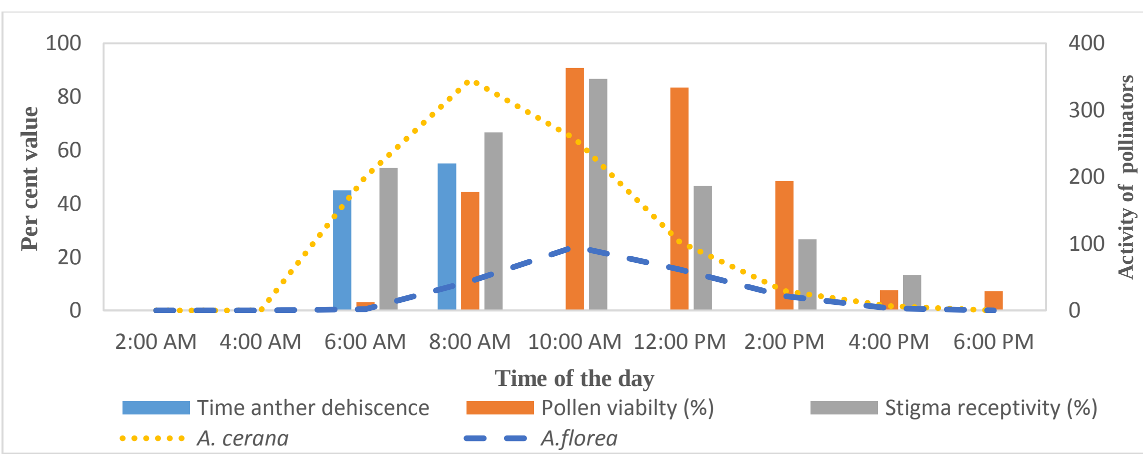


**Fig. 7: Comparison between time of anther dehiscence, pollen viability, stigma receptivity and activity of pollinators in summer-2015 season**

**Table 6: Pollen to ovule ratio per flower (n=25)**

| Sl. No. | No. of pollens | No. of ovules | Pollen: ovules/flower |
|---|---|---|---|
| **1** | 9480 | 58 | 163.45:1 |
| **2** | 11220 | 56 | 200.36:1 |
| **3** | 9560 | 57 | 167.72:1 |
| **4** | 9640 | 58 | 166.21:1 |
| **5** | 8438 | 58 | 145.48:1 |
| **6** | 10640 | 58 | 183.45:1 |
| **7** | 9934 | 56 | 177.39:1 |
| **8** | 10124 | 60 | 168.73:1 |
| **9** | 10384 | 58 | 179.03:1 |
| **10** | 10438 | 57 | 183.12:1 |
| **11** | 9704 | 57 | 170.25:1 |
| **12** | 10464 | 59 | 177.36:1 |
| **13** | 11258 | 58 | 194.10:1 |
| **14** | 9248 | 57 | 162.25:1 |
| **15** | 9138 | 58 | 157.55:1 |
| **16** | 11922 | 58 | 205.55:1 |
| **17** | 10578 | 56 | 188.89:1 |
| **18** | 9930 | 59 | 168.31:1 |
| **19** | 9675 | 59 | 163.98:1 |
| **20** | 11384 | 58 | 196.28:1 |
| **21** | 9560 | 60 | 159.33:1 |
| **22** | 11682 | 58 | 201.41:1 |
| **23** | 9964 | 58 | 171.79:1 |
| **24** | 9052 | 57 | 158.81:1 |
| **25** | 9920 | 58 | 171.03:1 |
| **Mean ± SD** | **10133.48±866.56** | **57.84±1.07** | **175.27±15.56: 1** |
| **Range** | **9052-11922** | **56-60** | **157.55-205.55** |
| | **Overall pollen: ovule/plant** | | **3154.86-3505.4** |

**Table 7: Per cent pollen germination across different times of the day during *kharif*-2014, *rabi*-2014 and *summer*-2015 season**

| Time | ***Kharif*-2014** | | | ***Rabi*-2014** | | | ***Summer*-2015** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Number of pollen kept for germination** | **No. of pollen germinated** | **% Germination** | **Number of pollen kept for germination** | **No. of pollen germinated** | **% Germination** | **Number of pollen kept for germination** | **No. of pollen germinated** | **% Germination** |
| **2:00AM** | 312 | 0 | **0.00** | 249 | 0 | **0.00** | 314 | 0 | **0.00** |
| **4:00AM** | 320 | 0 | **0.00** | 282 | 0 | **0.00** | 297 | 0 | **0.00** |
| **6:00AM** | 226 | 48 | **25.31** | 90 | 7 | **11.69** | 197 | 7 | **3.08** |
| **8:00AM** | 218 | 124 | **61.80** | 174 | 27 | **18.57** | 118 | 52 | **44.34** |
| **10:00AM** | 168 | 161 | **96.12** | 174 | 144 | **77.44** | 136 | 123 | **90.74** |
| **12:00PM** | 162 | 151 | **93.28** | 316 | 253 | **76.07** | 95 | 79 | **83.47** |
| **2:00PM** | 102 | 80 | **72.33** | 87 | 32 | **35.75** | 139 | 76 | **48.45** |
| **4:00PM** | 108 | 20 | **20.62** | 107 | 5 | **6.13** | 145 | 7 | **7.56** |
| **6:00PM** | 73 | 3 | **7.46** | 67 | 1 | **0.85** | 37 | 3 | **7.22** |

**Table 8: Stigma receptivity across different times of the day during *kharif*-2014, *rabi*-2014 and *summer*-2015 season**

| | | | | | | |
|---|---|---|---|---|---|---|
| ***Kharif*-2014** | | | | | | |
| **Time** | **Hand pollinated** | | | **Natural pollinated** | | |
| | **No. of flowers bagged** | **No. of fruit set** | **% fruit set** | **No. of flowers bagged** | **No. of fruit set** | **% fruit set** |
| **4:00 AM** | 30 | 0 | **0.00** | 30 | 0 | **0.00** |
| **6:00 AM** | 30 | 3 | **10.00** | 30 | 5 | **16.67** |
| **8:00 AM** | 30 | 10 | **33.33** | 30 | 10 | **33.33** |
| **10:00 AM** | 30 | 28 | **93.33** | 30 | 29 | **96.67** |
| **12:00 PM** | 30 | 21 | **70.00** | 30 | 25 | **83.33** |
| **2:00 PM** | 30 | 16 | **53.33** | 30 | 12 | **40.00** |
| **4:00 PM** | 30 | 4 | **13.33** | 30 | 3 | **10.00** |
| **6:00 PM** | 30 | 1 | **3.33** | 30 | 0 | **0.00** |
| ***Rabi*-2014** | | | | | | |
| **Time** | **Hand pollinated** | | | **Natural pollinated** | | |
| | **No. of flowers bagged** | **No. of fruit set** | **% fruit set** | **No. of flowers bagged** | **No. of fruit set** | **% fruit set** |
| **4:00 AM** | 30 | 0 | **0.00** | 30 | 0 | **0.00** |
| **6:00 AM** | 30 | 2 | **6.67** | 30 | 8 | **26.67** |
| **8:00 AM** | 30 | 16 | **53.33** | 30 | 17 | **56.67** |
| **10:00 AM** | 30 | 27 | **90.00** | 30 | 26 | **86.67** |
| **12:00 PM** | 30 | 21 | **70.00** | 30 | 24 | **80.00** |
| **2:00 PM** | 30 | 13 | **43.33** | 30 | 11 | **36.67** |
| **4:00 PM** | 30 | 4 | **13.33** | 30 | 2 | **6.67** |
| **6:00 PM** | 30 | 0 | **0.00** | 30 | 0 | **0.00** |
| ***Summer*-2015** | | | | | | |
| **Time** | **Hand pollinated** | | | **Natural pollinated** | | |
| | **No. of flowers bagged** | **No. of fruit set** | **% fruit set** | **No. of flowers bagged** | **No. of fruit set** | **% fruit set** |
| **4:00 AM** | 30 | 0 | **0.00** | 30 | 0 | **0.00** |
| **6:00 AM** | 30 | 5 | **16.67** | 30 | 16 | **53.33** |
| **8:00 AM** | 30 | 18 | **60.00** | 30 | 20 | **66.67** |
| **10:00 AM** | 30 | 24 | **80.00** | 30 | 26 | **86.67** |
| **12:00 PM** | 30 | 22 | **73.33** | 30 | 14 | **46.67** |
| **2:00 PM** | 30 | 6 | **20.00** | 30 | 8 | **26.67** |
| **4:00 PM** | 30 | 2 | **6.67** | 30 | 4 | **13.33** |
| **6:00 PM** | 30 | 0 | **0.00** | 30 | 0 | **0.00** |

flowers with peak stigma receptivity in mid-afternoon would get more deposition of pollen with greater density and diversity.

### 4.1.8 Nectar quantification

Nectar production in staminate flowers started around 06.00h onwards and continued till 18.00h. Initially nectar extraction was done at every two hour intervals, but after looking into the behaviour of flower visitors, nectar extraction was carried out at every one hour. The observations indicated that the production of nectar was maximum between 10.00 to 12.00h ($3.24 \pm 0.14$ µL per flower) but, the quantity of nectar produced per flower was increased to 7.08 µL upon frequent removal at every one hour interval (Table 9 and Fig. 8 and 9). Whereas the pistillate flowers did not produce any nectar.

Ramesh (2007) demonstrated that quantity of nectar gradually increased with the advancement of time and reached maximum at 09.00h in both pistillate and staminate flowers of ridge gourd, as in the current study. Similarly, in cucumber, the quantity of nectar and sugar concentration gradually increased with the advancement of time and reached maximum at 15.00h in both male and female flowers of cucumber and thereafter, decreased towards the end of the day (Rubina, 2010). She also revealed that, nectar production in both staminate and pistillate flowers remained more or less same from 08.00h to 18.00h with a peak production between 10.00 to 12.00h. The possible reason for continuous production might be to support and reward efficient foragers that are active throughout the day. In staminate flowers nectar production started after 06.00h and peak nectar production was around 10.00-12.00h which coincided with pollinator activity. Another interesting aspect regarding nectar production in bitter gourd is that the plant produces higher quantity of nectar in staminate flowers when removed frequently at one hour intervals.

## 4.2 Flower visitors of bitter gourd

A total of 27 species of flower visitors were recorded on bitter gourd belonging to 11 families of 3 orders. Of these, 16 were Hymenopterans (59.25 %), five belonged to Diptera (18.51 %) and six species to Lepidoptera (22.22 %). The order Hymenoptera was represented by 4 families including eight species of Apidae (50.00 %), six species of Halictidae (37.5 %), one species of Scolidae (6.25 %) and one species of Formicidae (6.25 %). Among the flower visitors, *Apis* bees (*A. cerana* and *A. florea*) were more abundant (70.13 %) when compared to other non-*Apis* species (29.86). Within these two *Apis* species, *A. cerana* (50.35 %) was more abundant than *A. florea* (19.77 %) (Table 10 and Plate 17, 18, 19, 20, 21, 22 and 23).

Bitter gourd is a cross-pollinated crop and requires small bees for effective transfer of pollens from male to the female flowers (Sands, 1928). Honey bees were observed to be the largest group (77.2%) of pollinating agents in cucurbits. Other insects such as ants (Tontz, 1944), thrips (Annand, 1926), beetles and solitary bees (Rosa, 1925; Alex, 1957; Joycox *et al*., 1975) have been identified as possible pollinators of cucurbits. The density of insects on flowers depends on several factors such as flower shape, size, colour, availability of floral rewards and weather conditions (Mevetty *et al.*, 1989). Insect pollinators have its specific ecological threshold level, below which activity does not

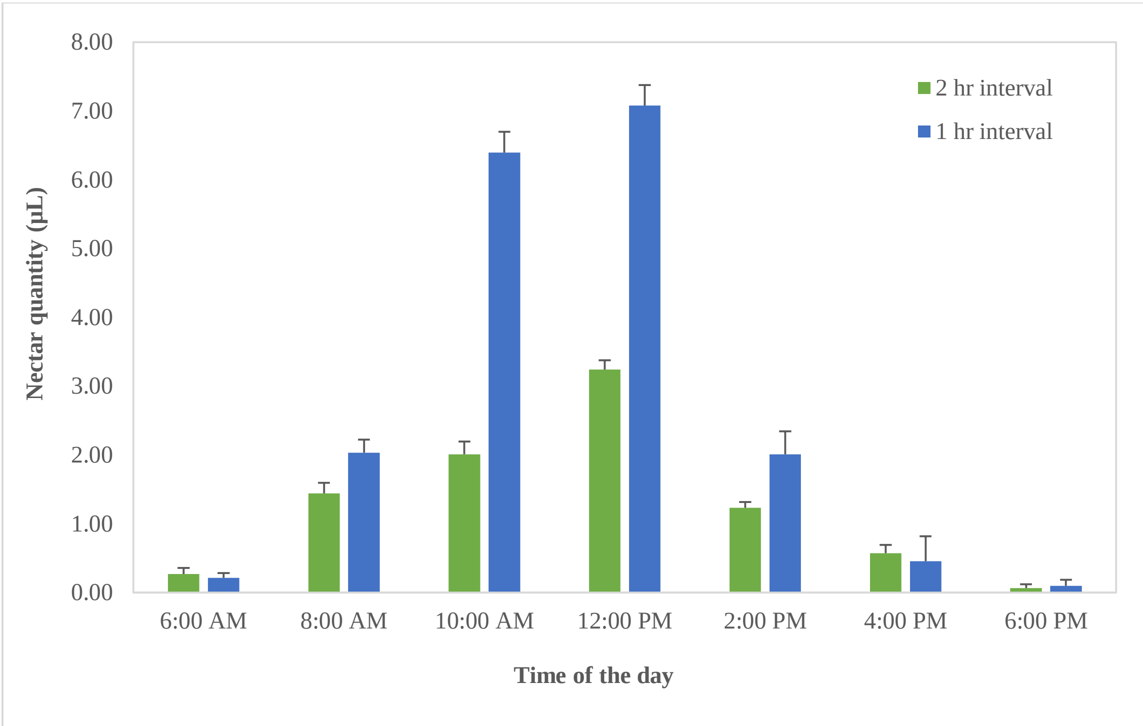


**Fig. 8: Quantity of nectar harvested from a single staminate flower in different times of a day**

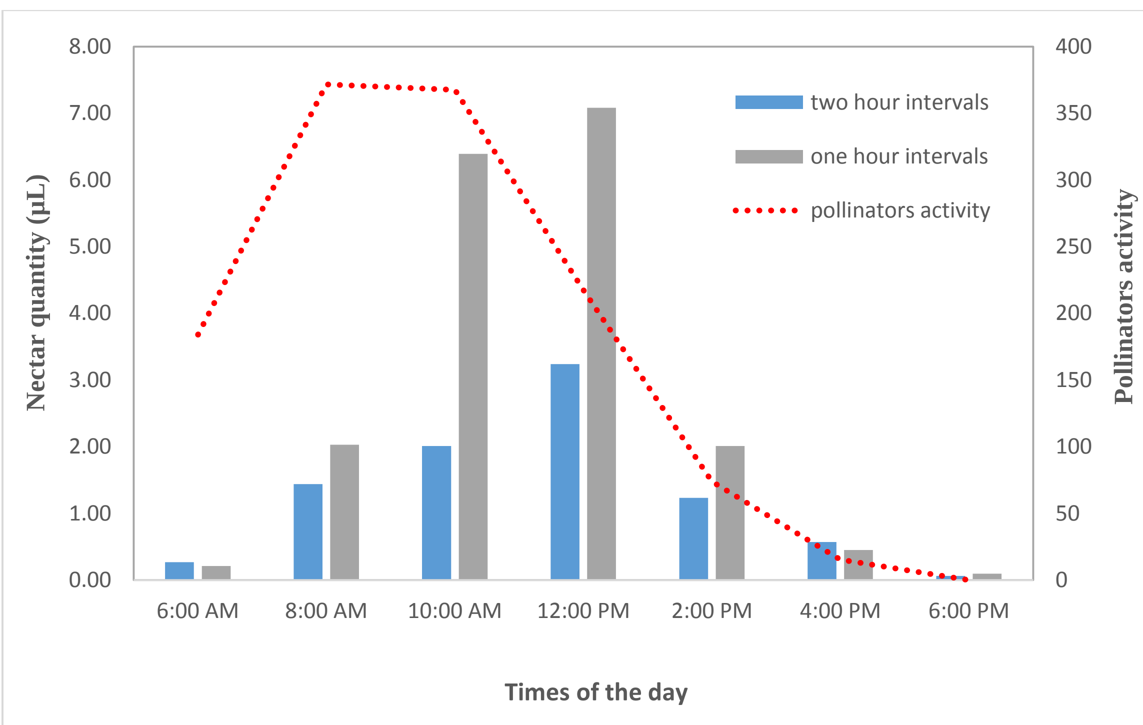


**Fig. 9: Comparison between nectar production and activity of efficient pollinators**

**Plate 17:** ***A. cerana*** **foraging bitter gourd flower**

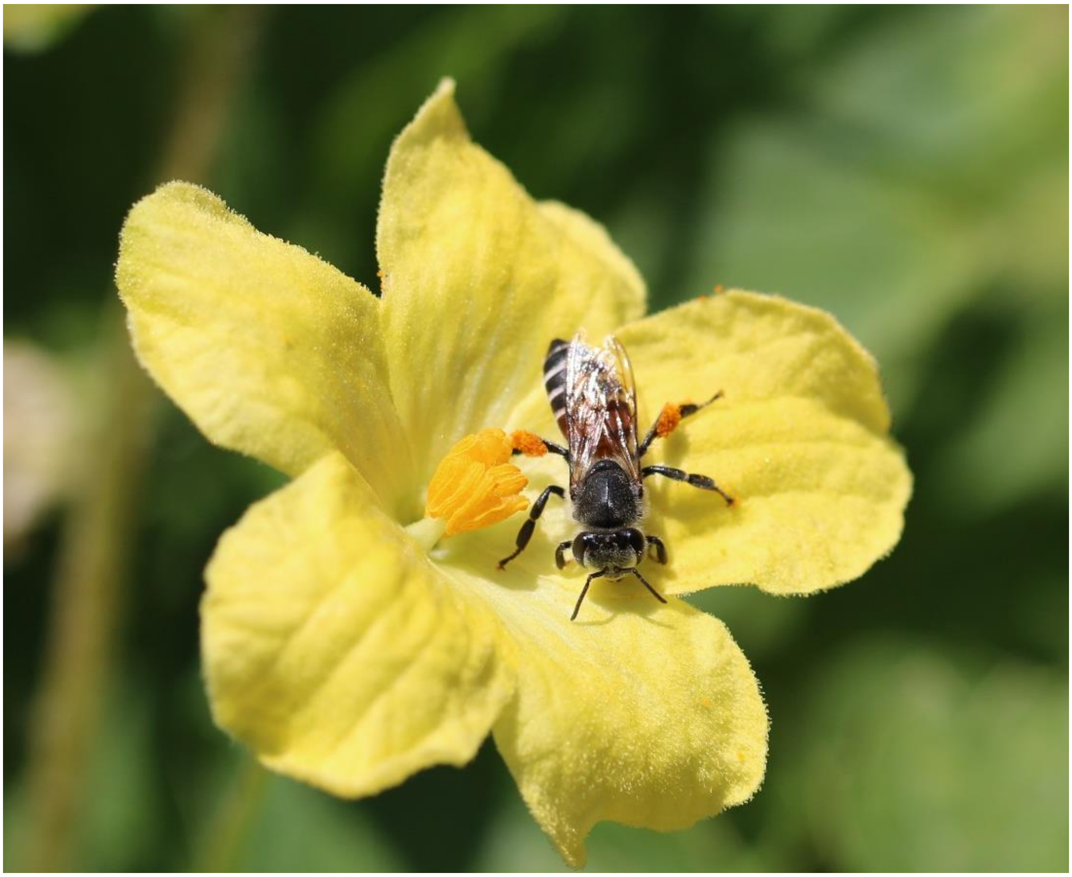

**Plate 18:** ***A. florea*** **foraging bitter gourd flower**

**Plate 19:** ***A. dorsata*** **foraging bitter gourd flower**

**Plate 20:** ***Tetragonula*** **sp. foraging bitter gourd flower**

**Plate 21:** ***Lasioglossum*** **sp. foraging bitter gourd flower**

**Plate 22:** ***Ceratina*** **sp. foraging bitter gourd flower**

*C. hieroglyphica*

*Lasioglossum* sp.1

*Lasioglossum* sp.2

*Lasioglossum* sp.3

*Nomoides sp.*

*I. scutellaris*

**Plate 23: Flower visitors (non-*Apis*) of bitter gourd flower**

**Table 9: Mean quantity of nectar produced in different times of the day (n=30 flowers)**

| Time | Mean amount of nectar harvested (µL) per flower from staminate flower | |
|---|---|---|
| | One hour intervals | Two hour intervals |
| 6:00 AM | 0.21±0.07 | 0.27±0.09 |
| 7:00 AM | 0.74±0.06 | |
| 8:00 AM | 1.29±0.13 | 1.44±0.15 |
| 9:00 AM | 3.08±0.12 | |
| 10:00 AM | 3.31±0.18 | 2.01±0.18 |
| 11:00 AM | 4.01±0.16 | |
| 12:00 PM | 3.07±0.13 | 3.24±0.14 |
| 1:00 PM | 1.16±0.15 | |
| 2:00 PM | 0.85±0.18 | 1.23±0.08 |
| 3:00 PM | 0.27±0.16 | |
| 4:00 PM | 0.18±0.20 | 0.57±0.12 |
| 5:00 PM | 0.07±0.04 | |
| 6.00 PM | 0.02±0.04 | 0.06±0.06 |
| 7.00 PM | 0.00±0.00 | |
| **Total** | **18.27±1.65** | **8.82±0.82** |

**Table 10: Pollinator species visiting bitter gourd flowers**

| Order | Family | Species | Reward |
|---|---|---|---|
| **Hymenoptera** | Apidae | *Apis cerana* Fab | *Nectar+Pollen* |
| | | *A. florea* Fab | *Nectar+Pollen* |
| | | *A. dorsata* Fab | *Nectar* |
| | | *Tetragonula iridipennis* Smith | *Nectar+Pollen* |
| | | *Ceratina hieroglyphica* Smith | *Nectar+Pollen* |
| | | *C. binghami* Cockrell | *Nectar+Pollen* |
| | | *Braunsapis sp.* | *Nectar+Pollen* |
| | | *Xylocopa aestuans* Linnaeus | *Nectar* |
| | Halictidae | *Lasioglossum* sp.1 | *Nectar+Pollen* |
| | | *Lasioglossum* sp.2 | *Nectar+Pollen* |
| | | *Lasioglossum* sp.3 | *Nectar+Pollen* |
| | | *Seladonia* sp. | *Nectar+Pollen* |
| | | *Nomoides* sp. | *Nectar+Pollen* |
| | | *Pachynomia* sp. | *Nectar+Pollen* |
| | Scolidae | Scolid wasp | *Pollen* |
| | Formicidae | *Camponotus sericeus* Fab | *Nectar* |
| **Diptera** | Syrphidae | *Ischiodon scuttellaris* Fab | *Pollen* |
| | | *Eristalinus tabanoides* Jaennicke | *Pollen* |
| | | *E. aeneus* Scopoli | *Pollen* |
| | Sarcophagidae | *Sarcophaga* sp. | *Pollen* |
| | Calliphoridae | *Chrysomya* sp. | *Pollen* |
| **Lepidoptera** | Lycaenidae | Blue butterfly | *Nectar* |
| | Pieridae | *Eurema hecabe* Linnaeus | *Nectar* |
| | | *Colotis etrida* Boisduval | *Nectar* |
| | | *Anaphaeis aurota* Fabricius | *Nectar* |
| | Nymphalidae | *Danus chrysippus* Linnaeus | *Nectar* |
| | Hesperidae | *Pelopidas mathias* Fabricius | *Nectar* |

occur. The ecological threshold required for a normal activity and its maintenance differ inter and intra-specificity depending upon the level of adaptability of a species in a given environment (Kapil and Jain, 1980). The daily flight activity varies with the time of the day and meteorological variables, especially wind, rainfall, temperature and humidity (Sarviva, 1985).

Grewal and Sidhu (1978 and 1979) reported *A. florea* as the predominant pollinator of bitter gourd followed by *A. dorsata*. They also reported Halictidae as pollinators in bitter gourd. Nidagundi and Sattagi (2005) reported that among the 10 species of pollinators in bitter gourd, *A. florea* was the most predominant, constituting 43.00 per cent of the total pollinators, followed by *A. cerana* (26.00 %), *A. dorsata* (13.00 %) and other pollinators (18.00 %). But, in the present study *A. cerana* was found to be the most frequent visitor of bitter gourd flowers.

Similar observations on the pollinator species of bitter gourd (*M. charantia*) were made by Deyto and Cervancia (2009) and stated that insects visiting the flowers of bitter gourd plant belonged to four different orders: Hymenoptera (*A. cerana*, *A. mellifera*, *Trigona* spp., *Halictus* spp., *Xylocopa* spp. and Formicidae), Lepidoptera (butterflies), Coleoptera (Chrysomelidae) and Diptera (*Calliphora* spp., Sarcophagidae and Syrphidae). Among these, honey bees (*A. mellifera* and *A. cerana*), stingless bees (*Trigona* spp.) and *Halictus* spp. were the major insect pollinators. According to Subhakar *et al.* (2011), a total of 17 species belonging to 10 families of four orders *viz.*, Hymenoptera, Lepidoptera, Diptera and Coleoptera were recorded foraging on bitter gourd. Among these, *T. iridipennis* Smith, *H. gutturosus* Vachal and *A. florea* were the most frequent. Mary *et al*. (2012) showed that species of pollinators of bitter gourd included Honey bees (*A. mellifera*), *Plebeian hildebrandti*, *Lasioglossum* sp. and Carpenter bees (*Xylocopa* spp.).

### 4.2.1 Abundance of flower visitors in bitter gourd (Visual counting method)

The data on visual counts of flower visitors with respect to their abundance in bitter gourd in all the three seasons revealed that *Apis* bees, *A. cerana* and *A. florea* were significantly larger in number and constituted nearly 65 per cent when compared to other non-*Apis* species visiting bitter gourd flowers. Within these two *Apis* species of flower visitors, *A. cerana* was more abundant than *A. florea* with per cent abundance of 50.42, 59.62 and 53.60 when compared to *A. florea* i.*e.*, 15.41, 11.79 and 13.34 in *kharif*-2014, *rabi*-2014 and *summer*-2015 seasons, respectively (Table 11, 12 and 13). The non-*Apis* species such as *Lasioglossum* spp. and *T. irridipennis* were found to be more active with per cent abundance of 10.83 and 9.34, respectively in *kharif*-2014; 8.72 and 7.44, respectively in *rabi*-2014 and 9.51 and 8.35, respectively in *summer*-2015 season (Fig. 10, 11 and 12).

According to McGregor and Todd (1952) bee foraging activity begins on the flower shortly after it opens, reaches a peak at about 11.00h and ceases by about 17.00h in cucurbit crops. In present study, *Lasioglossum* spp. and *T. irridipennis* increased with increase in floral abundance across flowering period of the crop in all seasons. The highest frequency of visitation at 25, 50, 75 and >90 per cent flower opening was 0.58,

**Table 11: Abundance of flower visitors (during 100% flowering) in bitter gourd in different times of the day during *Kharif*-2014**

| Time / Pollinator sp. | 06.00-07.00 h | 07.00-08.00 h | 08.00-09.00 h | 09.00-10.00 h | 10.00-11.00 h | 11.00-12.00 h | 12.00-13.00 h | 13.00-14.00 h | 14.00-15.00 h | 15.00-16.00 h | 16.00-17.00 h | 17.00-18.00 h | 18.00-19.00 h | Total | Mean± SD | % Bees |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***A. cerana*** | 24 | 98 | 116 | 85 | 77 | 65 | 28 | 22 | 16 | 8 | 1 | 0 | 0 | **540** | **41.54± 41.00** | **50.42** |
| ***A. florea*** | 0 | 3 | 6 | 12 | 16 | 30 | 42 | 31 | 21 | 2 | 1 | 1 | 0 | **165** | **12.69± 14.21** | **15.41** |
| ***A. dorsata*** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** | **0.08± 0.28** | **0.09** |
| ***Tetragonula* sp.** | 0 | 0 | 2 | 9 | 14 | 18 | 22 | 16 | 8 | 8 | 1 | 2 | 0 | **100** | **7.69± 7.69** | **9.34** |
| ***Lasioglossum* sp.** | 0 | 0 | 6 | 14 | 18 | 29 | 24 | 12 | 8 | 4 | 0 | 1 | 0 | **116** | **8.92± 9.84** | **10.83** |
| ***C. hieroglyphica*** | 0 | 0 | 0 | 1 | 0 | 3 | 6 | 12 | 2 | 1 | 0 | 0 | 0 | **25** | **1.92± 3.50** | **2.33** |
| ***Braunsapis* sp.** | 0 | 0 | 1 | 2 | 6 | 8 | 12 | 9 | 8 | 5 | 0 | 0 | 0 | **51** | **3.92± 4.27** | **4.76** |
| ***Nomia* sp.** | 0 | 0 | 0 | 1 | 2 | 7 | 8 | 7 | 2 | 1 | 0 | 0 | 0 | **28** | **2.15± 3.05** | **2.61** |
| **Scolids** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **1** | **0.08± 0.28** | **0.09** |
| **Lycanids** | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 0 | 0 | 0 | **10** | **0.77± 0.73** | **0.93** |
| **Pierids** | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 2 | 1 | 4 | 1 | 0 | 0 | **11** | **0.85± 1.14** | **1.03** |
| ***I. scuttellaris*** | 0 | 0 | 2 | 2 | 3 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | **13** | **1.00± 1.00** | **1.21** |
| **Dipteran sp.** | 0 | 0 | 0 | 0 | 2 | 3 | 1 | 3 | 1 | 0 | 0 | 0 | 0 | **10** | **0.77± 1.17** | **0.93** |

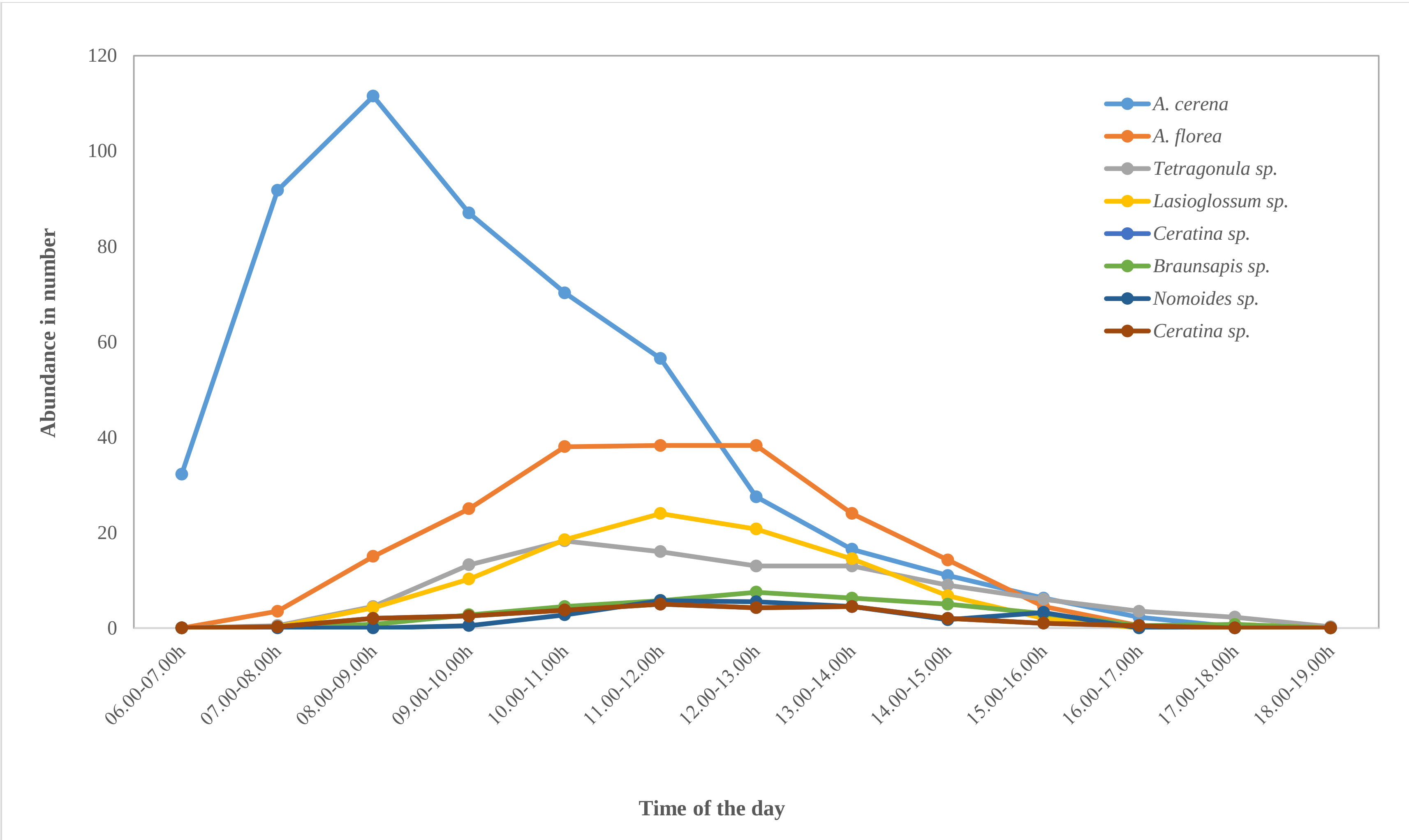


**Fig. 10: Abundance of flower visitors (during 100% flowering) in bitter gourd during different times of the day in *kharif*-2014 season**

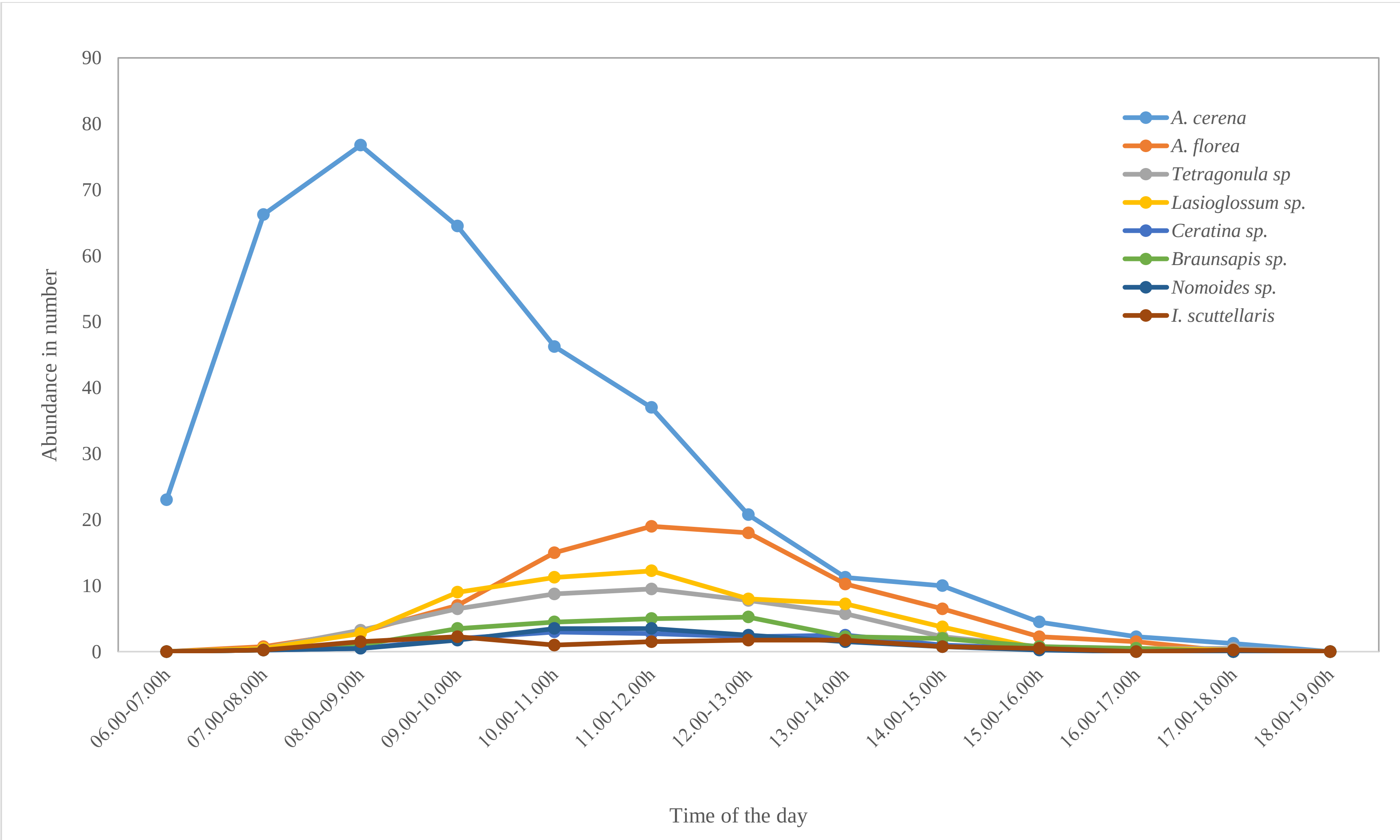


**Fig. 11: Abundance of flower visitors (during 100% flowering) in bitter gourd during different times of the day in *rabi*-2014 Season**

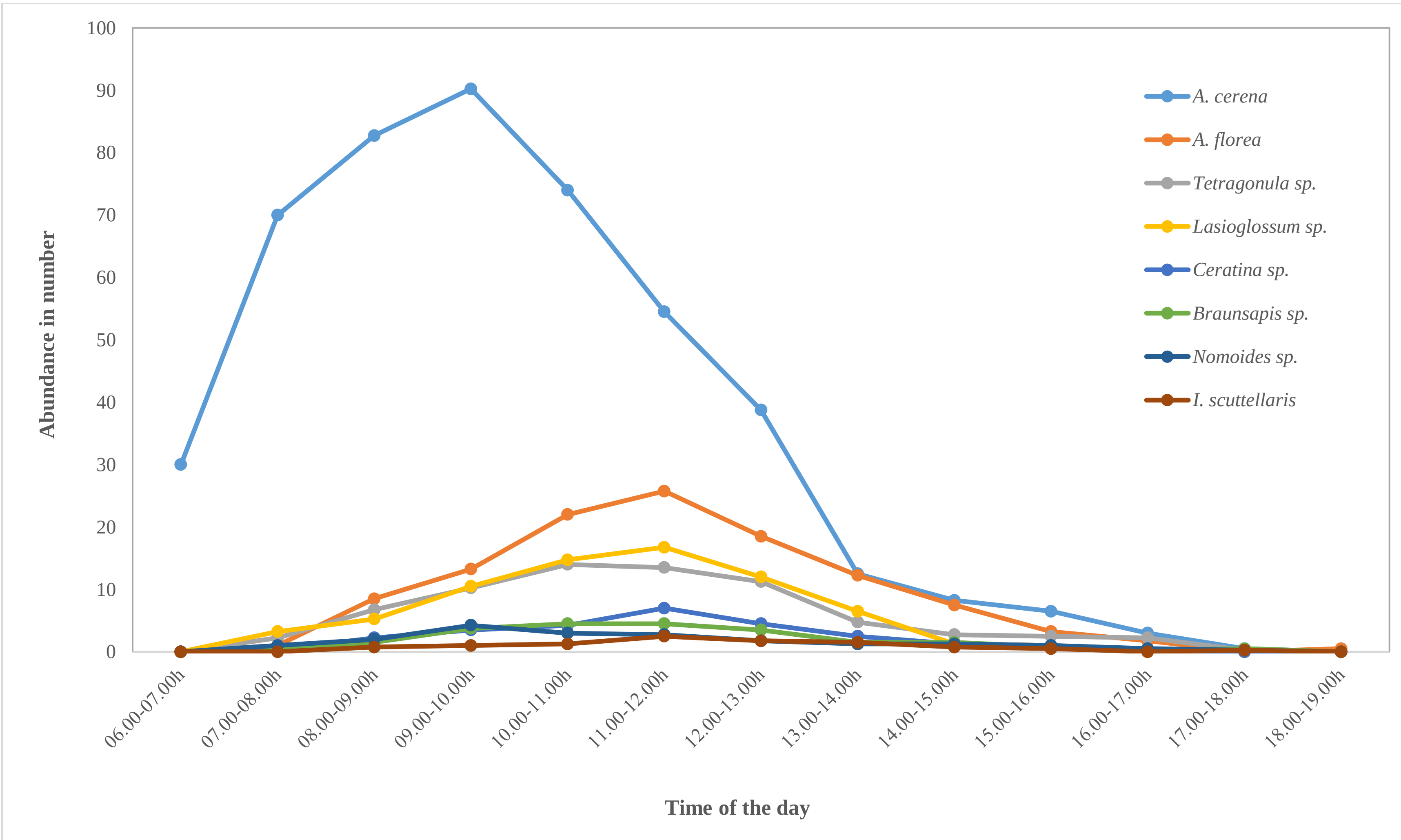


**Fig. 12: Abundance of flower visitors (during 100% flowering) in bitter gourd during different times of the day in *summer*-2015 season**

**Table 12: Abundance of flower visitors (during 100% flowering) in bitter gourd in different times of the day during *Rabi*-2014**

| Pollinator sp. / Time | 06.00-07.00 h | 07.00-08.00 h | 08.00-09.00 h | 09.00-10.00 h | 10.00-11.00 h | 11.00-12.00 h | 12.00-13.00 h | 13.00-14.00 h | 14.00-15.00 h | 15.00-16.00 h | 16.00-17.00 h | 17.00-18.00 h | 18.00-19.00 h | Total | Mean ±SD | % Bees |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***A. cerana*** | 28 | 84 | 89 | 76 | 62 | 51 | 28 | 18 | 16 | 8 | 4 | 1 | 0 | **465** | **35.77± 32.65** | **59.62** |
| ***A. florea*** | 0 | 0 | 2 | 10 | 22 | 26 | 15 | 8 | 6 | 2 | 1 | 0 | 0 | **92** | **7.08± 8.86** | **11.79** |
| ***A. dorsata*** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** | **0.00± 0.00** | **0.00** |
| ***Tetragonula* sp.** | 0 | 0 | 2 | 0 | 11 | 16 | 8 | 12 | 5 | 1 | 1 | 2 | 0 | **58** | **4.46± 5.49** | **7.44** |
| ***Lasioglossum* sp.** | 0 | 0 | 1 | 14 | 16 | 22 | 12 | 0 | 2 | 0 | 1 | 0 | 0 | **68** | **5.23± 7.80** | **8.72** |
| ***C. hieroglyphica*** | 0 | 0 | 0 | 2 | 4 | 6 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | **17** | **1.31± 2.06** | **2.18** |
| ***Braunsapis* sp.** | 0 | 0 | 2 | 4 | 8 | 4 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | **23** | **1.77± 2.39** | **2.95** |
| ***Nomia* sp.** | 0 | 0 | 1 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **5** | **0.38± 0.65** | **0.64** |
| **Scolids** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** | **0.00± 0.00** | **0.00** |
| **Lycanids** | 0 | 0 | 2 | 4 | 3 | 0 | 0 | 2 | 3 | 0 | 1 | 2 | 0 | **17** | **1.31± 1.44** | **2.18** |
| **Pierids** | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 2 | 1 | 4 | 1 | 0 | 0 | **11** | **0.85± 1.14** | **1.41** |
| ***I. scutellaris*** | 0 | 1 | 2 | 6 | 3 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | **17** | **1.31± 1.75** | **2.18** |
| **Dipteran sp.** | 0 | 0 | 0 | 4 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | **7** | **0.54± 1.13** | **0.90** |

**Table 13: Abundance of flower visitors (during 100% flowering) in bitter gourd in different times of the day during *Summer*-2015**

| Time / Pollinator sp. | 06.00-07.00 h | 07.00-08.00 h | 08.00-09.00 h | 09.00-10.00 h | 10.00-11.00 h | 11.00-12.00 h | 12.00-13.00 h | 13.00-14.00 h | 14.00-15.00 h | 15.00-16.00 h | 16.00-17.00 h | 17.00-18.00 h | 18.00-19.00 h | Total | Mean | % Bees |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***A. cerana*** | 28 | 46 | 92 | 98 | 85 | 56 | 42 | 8 | 4 | 1 | 1 | 1 | 0 | **462** | **35.54± 37.37** | **53.60** |
| ***A. florea*** | 0 | 0 | 1 | 9 | 12 | 34 | 27 | 14 | 10 | 4 | 3 | 0 | 1 | **115** | **8.85± 10.86** | **13.34** |
| ***A. dorsata*** | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** | **0.08± 0.28** | **0.12** |
| ***Tetragonula* sp.** | 0 | 1 | 4 | 9 | 12 | 18 | 15 | 8 | 3 | 2 | 0 | 0 | 0 | **72** | **5.54± 6.25** | **8.35** |
| ***Lasioglossum* sp.** | 0 | 4 | 2 | 8 | 18 | 22 | 18 | 7 | 2 | 1 | 0 | 0 | 0 | **82** | **6.31± 7.92** | **9.51** |
| ***C. hieroglyphica*** | 0 | 0 | 2 | 4 | 2 | 5 | 6 | 3 | 2 | 1 | 0 | 0 | 0 | **25** | **1.92± 2.06** | **2.90** |
| ***Braunsapis* sp.** | 0 | 0 | 1 | 6 | 8 | 5 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | **22** | **1.69± 2.78** | **2.55** |
| ***Nomia* sp.** | 0 | 0 | 2 | 2 | 6 | 4 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | **19** | **1.46± 1.85** | **2.20** |
| **Scolids** | 0 | 2 | 1 | 1 | 1 | 3 | 1 | 1 | 5 | 1 | 0 | 0 | 0 | **16** | **1.23± 1.42** | **1.86** |
| **Lycanids** | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | **8** | **0.62± 0.51** | **0.93** |
| **Pierids** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** | **0.00± 0.00** | **0.00** |
| ***I. scuttellaris*** | 0 | 0 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | **10** | **0.77± 0.73** | **1.16** |
| **Dipteran sp.** | 0 | 0 | 0 | 0 | 2 | 3 | 1 | 3 | 1 | 0 | 0 | 0 | 0 | **10** | **0.77± 1.17** | **1.16** |

0.55, 0.52, 0.43, respectively in *kharif*-2014 season, whereas during *rabi*-2014 season it was 0.63, 0.59, 0.62 and 0.56, respectively and 0.66, 0.60, 0.56 and 0.54, respectively in *summer*-2015 season by *A. cerana* when compare to all other pollinators in all three seasons (Table 14 and Fig. 13).

Among three seasons, the overall abundance of flower visitors was more in *kharif*-2014 when compared to *summer*-2015 and least abundance was observed during *rabi*-2014. This may be due to influence of weather parameters on pollinator activity. The visual counting method was the most reliable to record species and abundance of flower visitors for pollination biology studies.

### 4.2.2 Abundance of flower visitors in bitter gourd (Bee bowl collection, yellow pan, Malaise trap and Intercept trap method)

The results from bee bowl and yellow pan collection showed that *A. cerana*, *A. florea*, *Lasioglossum* sp. 1, *Lasioglossum* sp. 2, *Lasioglossum* sp. 3, *Braunsapis* sp., *Nomia* sp., *C. hieroglyphica*, *C. binghami*, syrphids and other Dipterans were abundant with over all mean of 2.37±1.99, 1.67±1.45, 1.08±0.86, 1.67±1.45, 0.75±0.47, 0.83±0.49, 0.96±0.60, 0.79±0.49, 0.67±0.41, 0.25±0.27 and 3.42±3.46, respectively in *kharif* -2014 (Table 15).

The results from the bee bowl, yellow pan, malaise trap and intercept trap collection showed that both *A. florea* and *A. cerana* and also Non-*Apis* species like *Lasioglossum* sp. 1, *Lasioglossum* sp. 2, *Lasioglossum* sp. 3, *Braunsapis* sp., *Nomia* sp., *C. hieroglyphica*, *C. binghami*, syrphids and other Dipterans were abundant. The overall mean collection of *A. florea* and *A. cerana* was 1.25±0.95 and 0.75±0.73 per trap, respectively in *rabi*-2014, whereas in *summer*-2015 it was 1.53±1.29 and 1.09±1.10 per trap, respectively. The overall mean collection of *Lasioglossum* sp. 1, *Lasioglossum* sp. 2, *Lasioglossum* sp. 3, *Braunsapis* sp., *Nomia* sp., *C. hieroglyphica*, *C. binghami* and syrphids during *rabi*-2014 were 0.84±0.79, 1.09±0.84, 0.38±0.44, 0.47±0.31, 0.47±0.36, 0.22±0.21, 0.34±0.38 and 0.16±0.30 per trap respectively, whereas the overall mean collection of 0.78±0.75, 1.06±0.82, 0.72±0.62, 0.63±0.50, 0.44±0.37, 0.41±0.38, 0.53±0.39 and 0.19±0.29 per trap for *Lasioglossum* sp. 1, *Lasioglossum* sp. 2, *Lasioglossum* sp. 3, *Braunsapis* sp., *Nomia* sp., *C. hieroglyphica*, *C. binghami* and syrphids, respectively was observed in *summer*-2015 (Table 16 and 17).

The different colours of bee bowls and yellow pan traps were evaluated to record attraction for flower visitors. Among the traps, yellow pan trap collected highest number of bees with a mean collection of 2.70 ± 2.77, 1.20 ± 0.84 and 1.68 ± 1.15 followed by yellow coloured bowl with a mean collection of 2.05 ±1.37, 1.14 ± 0.91 and 1.57 ± 1.17 in *kharif*-2014, *rabi*-2014 and *summer*-2015 seasons, respectively. The blue and white coloured bowls recorded with a mean collection of 1.02 ± 0.68 and 1.52 ± 0.88 respectively in *kharif*-2014, 0.93 ± 1.00 and 1.07 ± 0.89, respectively in *rabi*-2014 and 0.98 ± 0.45 and 0.91 ± 0.41, respectively in *summer*-2015. The green and gray coloured bee bowls attracted least number of flower visitors in all the three seasons (Table 15, 16 and 17). The present study is in agreement with Revanasidda (2015) who also recorded that *A. florea* and *A. cerana* and non-*Apis* species like *Ceratina hieroglyphica*,

**Table 14: Frequency of visitation by different species of flower visitors in bitter gourd in different weeks at different per cent flower open during *Kharif*-2014, *Rabi*-2014 and *Summer*-2015**

| Season / Visiting sp. | *Kharif*-2014 | | | | *Rabi*-2014 | | | | *Summer*-2015 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25 % Flower opening | 50 % Flower opening | 75 % Flower opening | >90 % Flower opening | 25 % Flower opening | 50 % Flower opening | 75 % Flower opening | >90 % Flower opening | 25 % Flower opening | 50 % Flower opening | 75 % Flower opening | >90 % Flower opening |
| ***A. cerana*** | 0.58 | 0.55 | 0.52 | 0.43 | 0.63 | 0.59 | 0.62 | 0.56 | 0.66 | 0.60 | 0.56 | 0.54 |
| ***A. florea*** | 0.13 | 0.16 | 0.16 | 0.28 | 0.17 | 0.17 | 0.12 | 0.12 | 0.14 | 0.16 | 0.14 | 0.13 |
| ***Tetragonula* sp.** | 0.13 | 0.10 | 0.10 | 0.08 | 0.04 | 0.05 | 0.08 | 0.10 | 0.06 | 0.08 | 0.10 | 0.10 |
| ***Lasioglossum* sp.** | 0.10 | 0.11 | 0.11 | 0.09 | 0.05 | 0.07 | 0.09 | 0.12 | 0.06 | 0.06 | 0.09 | 0.11 |
| ***Ceratina* sp.** | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.04 |
| ***Braunsapis* sp.** | 0.02 | 0.03 | 0.05 | 0.04 | 0.04 | 0.04 | 0.03 | 0.04 | 0.02 | 0.02 | 0.03 | 0.03 |
| ***Nomoides sp.*** | 0.01 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| ***I. scuttellaris*** | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 | 0.02 |

***Mean of four sampling days***

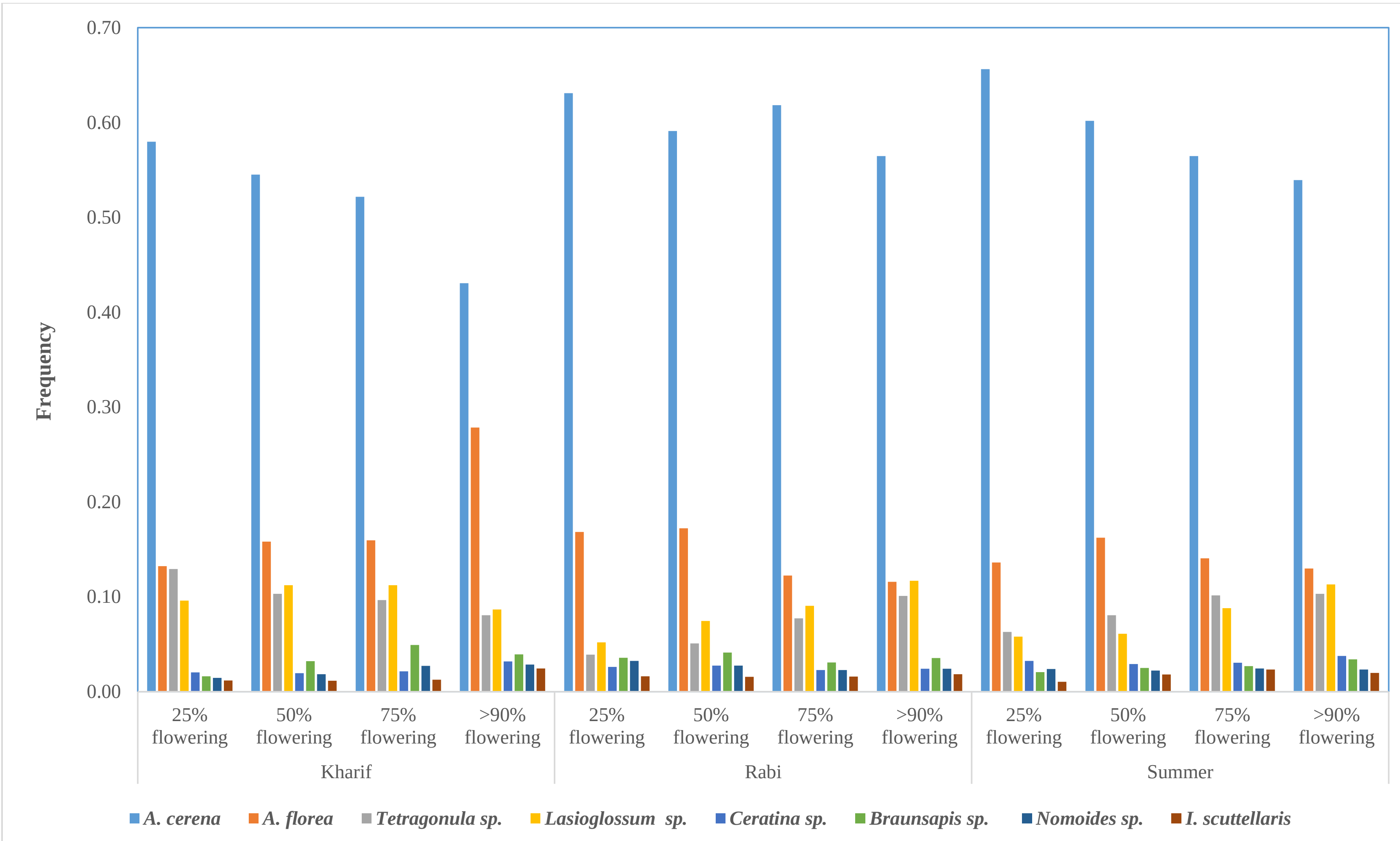


**Fig. 13: Frequency of flower visitors in bitter gourd in different weeks (average of four sampling day data) representing different per cent of flower opening in *kharif*-2014, *rabi*-2014 and *summer*-2015 season**

**Table 15: Abundance and flower visitors in bitter gourd (bee bowl collection) during *Kharif*-2014**

| Bee bowl colour / Pollinator sp. | Yellow | Blue | Gray | White | Green | Yellow pan | Overall Mean ± SD |
|---|---|---|---|---|---|---|---|
| ***A. cerana*** | 4.50±3.51 | 1.25±0.96 | 0.50±0.58 | 2.50±1.29 | 0.50±1.00 | 5.00±4.08 | **2.37±1.99** |
| ***A. florea*** | 3.50±2.65 | 1.00±0.82 | 0.00±0.00 | 1.75±1.26 | 0.50±0.58 | 3.25±3.40 | **1.67±1.45** |
| ***Lasioglossum* sp1** | 1.75±2.22 | 1.25±0.50 | 0.00±0.00 | 1.75±0.50 | 0.00±0.00 | 1.75±2.22 | **1.08±0.86** |
| ***Lasioglossum* sp2** | 3.50±2.65 | 1.75±0.50 | 0.50±0.58 | 1.00±0.82 | 0.00±0.00 | 3.25±2.06 | **1.67±1.45** |
| ***Lasioglossum* sp3** | 1.00±1.15 | 0.50±0.58 | 0.25±0.50 | 1.25±0.50 | 0.25±0.50 | 1.25±1.50 | **0.75±0.47** |
| ***Braunsapis sp.*** | 1.25±1.26 | 1.00±0.82 | 0.50±0.58 | 0.50±0.58 | 0.25±0.50 | 1.50±1.00 | **0.83±0.49** |
| ***Nomia sp.*** | 1.25±0.96 | 0.75±0.50 | 0.00±0.00 | 1.75±0.96 | 0.75±0.50 | 1.25±0.96 | **0.96±0.60** |
| ***C. hieroglyphica*** | 1.25±0.50 | 0.75±0.50 | 0.00±0.00 | 1.00±0.82 | 0.50±0.58 | 1.25±0.50 | **0.79±0.49** |
| ***C. binghami*** | 0.75±0.50 | 0.50±0.58 | 0.00±0.00 | 1.25±0.96 | 0.75±0.50 | 0.75±0.50 | **0.67±0.41** |
| **Syrphids** | 0.50±1.00 | 0.00±0.00 | 0.00±0.00 | 0.50±1.00 | 0.00±0.00 | 0.50±1.00 | **0.25±0.27** |
| **Dipteran sp.** | 3.25±2.50 | 2.50±0.58 | 0.50±1.00 | 3.50±1.29 | 0.75±0.96 | 10.00±3.65 | **3.42±3.46** |
| **Total** | **22.50** | **11.25** | **2.25** | **16.75** | **4.25** | **29.75** | |
| **Mean± SD** | **2.05±1.37** | **1.02±0.68** | **0.20±0.25** | **1.52±0.88** | **0.39±0.30** | **2.70±2.77** | |

***Each cell carries mean of 4 sampling days representing 4 weeks***

**Table 16: Abundance and flower visitors in bitter gourd (bee bowl, yellow pan, malaise trap and intercept trap collection) during *Rabi*-2014**

| Pollinator sp. \ Bee bowl colour and trap | Yellow | Blue | Gray | White | Green | Yellow pan | Malise trap | Intercept trap | Overall Mean ± SD |
|---|---|---|---|---|---|---|---|---|---|
| ***A. cerana*** | 3.00±1.83 | 1.25±0.96 | 0.75±0.96 | 1.00±0.82 | 1.25±0.96 | 2.25±1.26 | 0.25±0.50 | 0.25±0.50 | **1.25±0.95** |
| ***A. florea*** | 1.00±0.82 | 0.75±0.50 | 0.00±0.00 | 1.75±0.96 | 0.75±0.50 | 1.75±0.96 | 0.00±0.00 | 0.00±0.00 | **0.75±0.73** |
| ***Lasioglossum* sp1** | 1.50±1.29 | 1.75±0.96 | 0.25±0.50 | 1.25±0.50 | 0.25±0.50 | 1.75±1.71 | 0.00±0.00 | 0.00±0.00 | **0.84±0.79** |
| ***Lasioglossum* sp2** | 1.75±0.96 | 1.75±1.71 | 0.75±0.50 | 1.50±0.58 | 0.75±0.50 | 2.25±1.50 | 0.00±0.00 | 0.00±0.00 | **1.09±0.84** |
| ***Lasioglossum* sp3** | 1.00±1.15 | 0.00±0.00 | 0.50±1.00 | 0.50±0.58 | 0.00±0.00 | 1.00±0.82 | 0.00±0.00 | 0.00±0.00 | **0.38±0.44** |
| ***Braunsapis* sp.** | 0.75±0.50 | 0.50±0.58 | 0.50±0.58 | 0.75±0.50 | 0.50±0.58 | 0.75±0.50 | 0.00±0.00 | 0.00±0.00 | **0.47±0.31** |
| ***Nomia* sp.** | 0.50±0.58 | 0.50±0.58 | 0.25±0.50 | 0.75±0.50 | 0.75±0.50 | 1.00±0.82 | 0.00±0.00 | 0.00±0.00 | **0.47±0.36** |
| ***C. hieroglyphica*** | 0.25±0.50 | 0.50±0.58 | 0.00±0.00 | 0.25±0.50 | 0.50±0.58 | 0.25±0.50 | 0.00±0.00 | 0.00±0.00 | **0.22±0.21** |
| ***C. binghami*** | 0.50±0.58 | 0.00±0.00 | 0.25±0.50 | 0.75±0.50 | 1.00±0.00 | 0.25±0.50 | 0.00±0.00 | 0.00±0.00 | **0.34±0.38** |
| **syrphids** | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.50±0.58 | 0.00±0.00 | 0.75±0.96 | 0.00±0.00 | **0.16±0.30** |
| **Dipteran sp.** | 2.25±1.89 | 3.25±2.36 | 1.00±0.82 | 3.25±1.26 | 1.00±0.00 | 2.00±1.41 | 3.75±5.56 | 1.75±2.36 | **2.28±1.05** |
| **Total** | **12.50** | **10.25** | **4.25** | **11.75** | **7.25** | **13.25** | **4.75** | **2.00** | |
| **Mean± SD** | **1.14±0.91** | **0.93±1.00** | **0.39±0.34** | **1.07±0.89** | **0.66±0.36** | **1.20±0.84** | **0.43±1.12** | **0.18±0.53** | |

***Each cell carries mean of 4 sampling days representing 4 weeks***

**Table 17: Abundance and flower visitors in bitter gourd (bee bowl, malaise trap and intercept trap collection) during *Summer*-2015**

| Bee bowl colour and trap / Pollinator sp. | Yellow | Blue | Gray | White | Green | Yellow pan | Malise trap | Intercept trap | Overall Mean± SD |
|---|---|---|---|---|---|---|---|---|---|
| ***A. cerana*** | 3.75±1.71 | 1.25±0.96 | 1.00±0.82 | 1.25±0.50 | 1.25±0.96 | 3.25±2.63 | 0.25±0.50 | 0.25±0.50 | **1.53±1.29** |
| ***A. florea*** | 3.00±1.63 | 1.50±1.29 | 0.25±0.50 | 1.25±0.96 | 0.25±0.50 | 2.25±0.96 | 0.25±0.50 | 0.00±0.00 | **1.09±1.10** |
| ***Lasioglossum* sp1** | 1.00±0.82 | 1.00±0.82 | 0.25±0.50 | 1.25±0.50 | 0.25±0.50 | 2.25±2.06 | 0.25±0.50 | 0.00±0.00 | **0.78±0.75** |
| ***Lasioglossum* sp2** | 2.00±0.82 | 1.25±0.96 | 0.75±0.50 | 0.75±0.50 | 0.75±0.50 | 2.50±1.00 | 0.50±0.58 | 0.00±0.00 | **1.06±0.82** |
| ***Lasioglossum* sp3** | 1.50±1.73 | 0.50±0.58 | 0.50±1.00 | 1.25±0.96 | 0.50±0.58 | 1.50±1.29 | 0.00±0.00 | 0.00±0.00 | **0.72±0.62** |
| ***Braunsapis* sp.** | 1.25±0.96 | 1.00±0.82 | 0.50±0.58 | 0.50±0.58 | 0.50±0.58 | 1.25±0.96 | 0.00±0.00 | 0.00±0.00 | **0.63±0.50** |
| ***Nomia* sp.** | 0.75±0.50 | 0.75±0.50 | 0.00±0.00 | 0.75±0.50 | 0.50±0.58 | 0.75±0.50 | 0.00±0.00 | 0.00±0.00 | **0.44±0.37** |
| ***C. hieroglyphica*** | 0.50±0.58 | 0.50±0.58 | 0.00±0.00 | 1.00±0.82 | 0.75±0.50 | 0.50±0.58 | 0.00±0.00 | 0.00±0.00 | **0.41±0.38** |
| ***C. binghami*** | 0.75±0.50 | 1.00±0.82 | 0.25±0.50 | 0.75±0.96 | 0.75±0.50 | 0.75±0.50 | 0.00±0.00 | 0.00±0.00 | **0.53±0.39** |
| **Syrphids** | 0.00±0.00 | 0.25±0.50 | 0.00±0.00 | 0.00±0.00 | 0.50±0.58 | 0.00±0.00 | 0.75±0.96 | 0.00±0.00 | **0.19±0.29** |
| **Dipteran sp.** | 2.75±1.50 | 1.75±0.96 | 1.25±0.50 | 1.25±0.50 | 2.00±2.16 | 3.50±1.91 | 5.50±4.04 | 0.50±0.58 | **2.31±1.59** |
| **Total** | **17.25** | **10.75** | **4.75** | **10.00** | **8.00** | **18.50** | **7.50** | **0.75** | |
| **Mean± SD** | **1.57±1.17** | **0.98±0.45** | **0.43±0.42** | **0.91±0.41** | **0.73±0.51** | **1.68±1.15** | **0.68±1.62** | **0.07±0.16** | |

***Each cell carries mean of 4 sampling days representing 4 weeks***

*C. binghami*, *Lasioglossum* spp. and *Nomia* sp. In abundance with bee bowls and conformed that yellow, blue and white color bowls were more efficient for pollinator collection than green and grey ones.

The malise and intercept traps were also used to record flower visitors in *rabi* and *summer* seasons. Both malaise and intercept traps caught very low number of flower visitors with a mean collection of 0.43 ± 1.12 and 0.18 ± 0.53, respectively in *rabi*-2014 and 0.68 ± 1.62 and 0.07 ± 0.16, respectively in *summer*-2015 season (Table 16 and 17).

The bee bowl, yellow pan, malaise trap and intercept trap collection may be suitable to record the species of the flower visitors that are missed from visual counting. Among different traps evaluated to record flower visitors, yellow pan trap followed by yellow bee bowl were more efficient when compared to remaining traps in all the three seasons (Fig. 14 and 15).

**4.2.3 Diversity of flower visitors**

The data on the abundance of bee species and their diversity in different times of day and in different weeks were used to calculate the Shannon-Wiener Diversity Index. In *kharif*-2014, *rabi*-2014 and *summer*-2015 seasons, the maximum pollinator diversity remained same between 08.00 to 14.00h except between 06.00 to 07.00h and later the activity decreased gradually (Fig. 16).

Diversity was also calculated for flower visitors across different weeks representing different flowering percentage. In all the three seasons, the diversity was less in first week but later increased with increase in per cent flowering. The "H" values at 25, 50, 75 and >90 per cent flowering during *kharif*-2014, *rabi*-2014 and *summer*-2015 seasons were 0.58, 0.55 and 0.53, respectively; 0.61, 0.59 and 0.58, respectively; 0.65, 0.57 and 0.62, respectively and 0.68, 0.62 and 0.64, respectively (Table 18, 19 and 20).

The dominance (in numbers) of species during the flowering season varied within the season. Among all the species of flower visitors during *kharif*-2014, *rabi*-2014 and *summer*-2015 seasons, *A. cerana* was more dominant (d = 0.43 to 0.58, d= 0.56 to 0.63 and d=0.54 to 0.66, respectively) followed by *A. florea* (d = 0.13 to 0.28, d= 0.12 to 0.17 and 0.13 to 0.14, respectively). The dominance (d) of major species decreased with increase in flowering percentage across different weeks (Table 21, 22 and 23). Another interesting aspect in bitter gourd ecosystem is that the pollinator abundance increased with increase in flower numbers which indicates a direct relation between pollinator's abundance, diversity and floral abundance (Fig. 16). Berger-Parker Dominance Index indicated *A. cerana* to be the most dominant species followed by *A. florea* in all the three seasons and also dominance of foragers decreased and abundance increased as per cent flowering increased.

The diurnal and seasonal activity of the most frequent and reliable floral visitors varied during the day and the season. The probable reason may be environmental variation in temperature, light intensity, wind speed and relative humidity, as well as plant characteristics including floral structure and the spatial and temporal arrangement

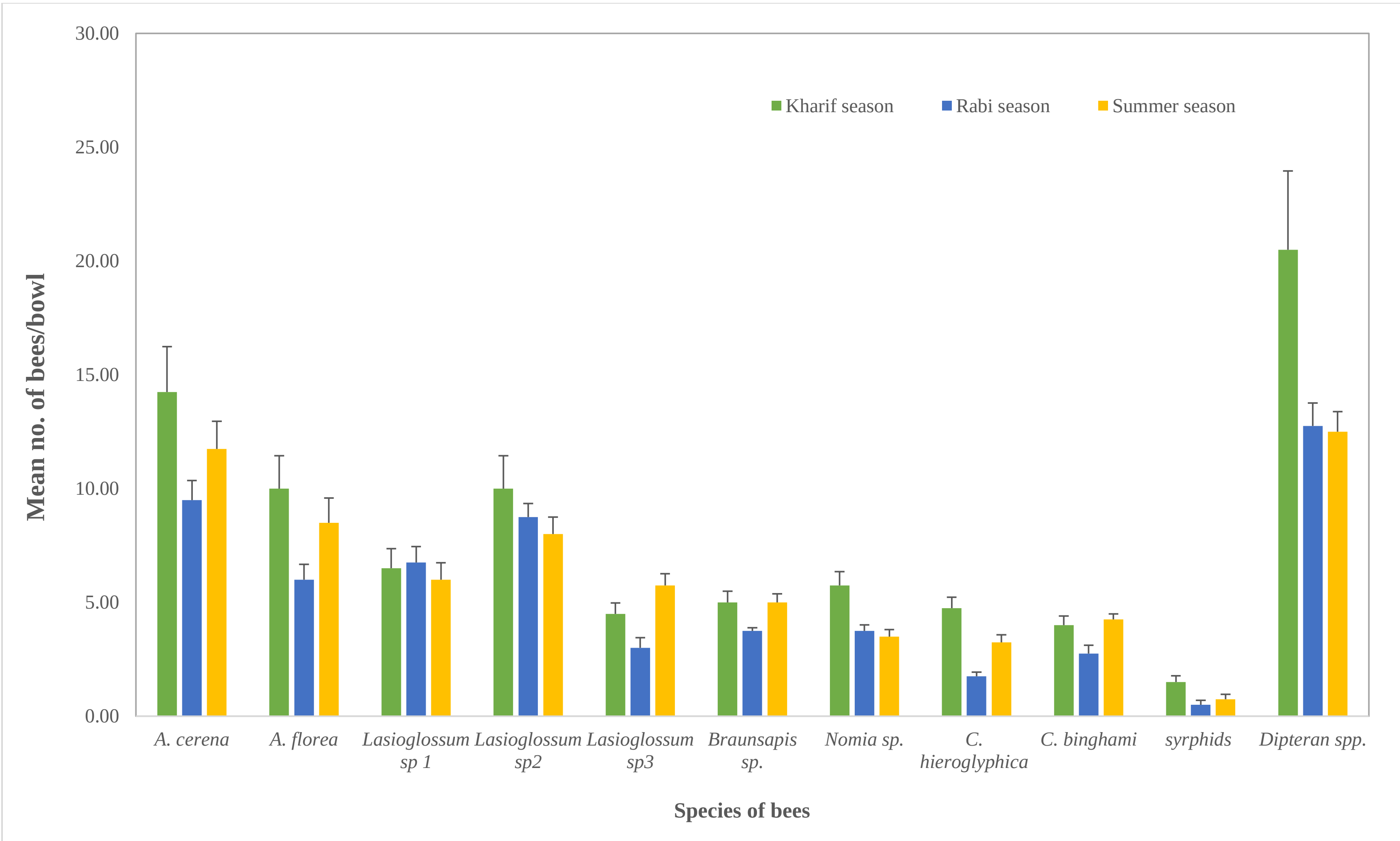


**Fig. 14: Abundance of flower visitors in (bee bowl) bitter gourd during different times of the day in *kharif*-2014, *rabi*-2014 and *summer*-2015 season**

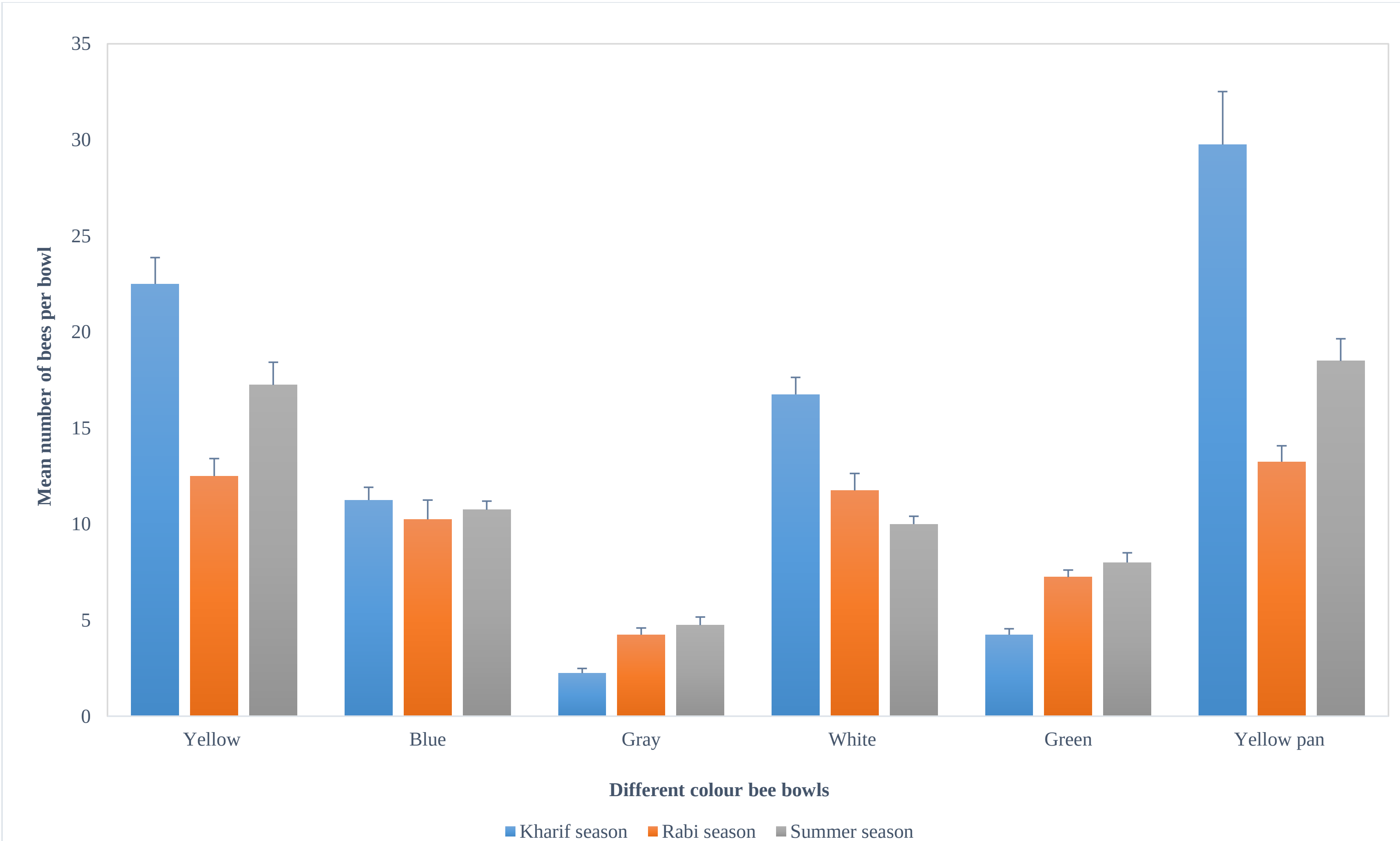


**Fig. 15: Comparison of different colours of bee bowls for attraction and collection of flower visitors of bitter gourd (n=5 bowls/colour/sampling day)**

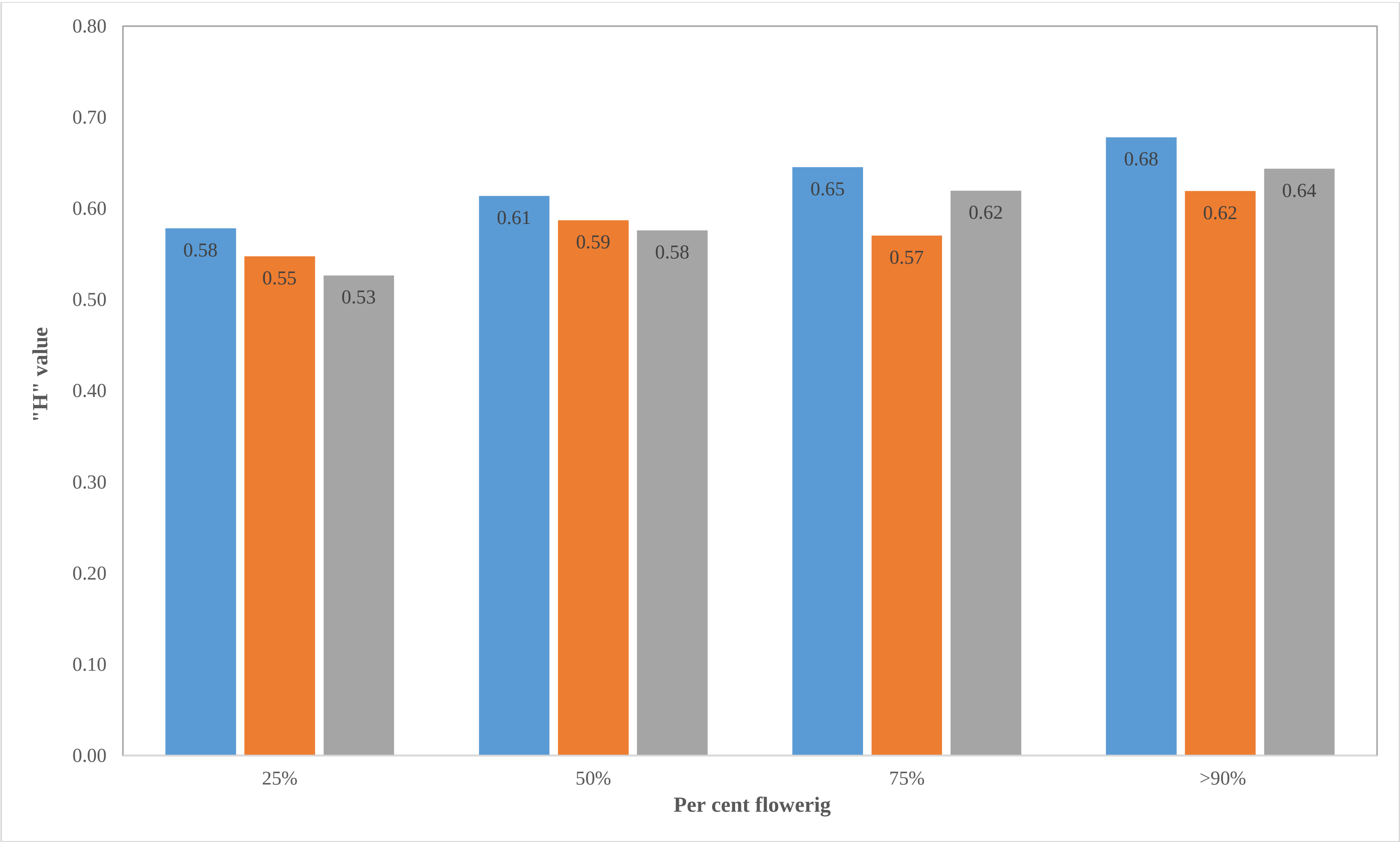


**Fig. 16: Shannon-Wiener diversity index (H) for flower visitors across different weeks representing different flowering percentage in bitter gourd in *kharif*-2014, *rabi*-2014 and *summer*-2015 season**

**Table 18: Shannon-Weaver index of diversity (H) for flower visitors during different weeks representing different per cent flowering during *Kharif*-2014**

| Pollinators sp. / % flowering | *A. cerena* | *A. florea* | *T. iridipennis* | *Lasioglossum* sp. | *Ceratina* sp. | *Braunsapis* sp. | *Nomia* sp. | *I. scuttellaris* | "H" value |
|---|---|---|---|---|---|---|---|---|---|
| **25%** | 399 | 91 | 89 | 66 | 14 | 11 | 10 | 8 | **0.58** |
| **50%** | 476 | 138 | 90 | 98 | 17 | 28 | 16 | 10 | **0.61** |
| **75%** | 540 | 165 | 100 | 116 | 22 | 51 | 28 | 13 | **0.65** |
| **>90%** | 637 | 412 | 119 | 128 | 47 | 58 | 42 | 36 | **0.68** |

***Mean of four sampling days***

**Table 19: Shannon-Weaver index of diversity (H) for flower visitors during different weeks representing different per cent flowering during *Rabi*-2014**

| Pollinators sp. / % flowering | *A. cerana* | *A. florea* | *T. iridipennis* | *Lasioglossum sp.* | *Ceratina sp.* | *Braunsapis sp.* | *Nomia sp.* | *I. scuttellaris* | "H" value |
|---|---|---|---|---|---|---|---|---|---|
| **25%** | 399 | 91 | 89 | 66 | 14 | 11 | 10 | 8 | **0.55** |
| **50%** | 476 | 138 | 90 | 98 | 17 | 28 | 16 | 10 | **0.59** |
| **75%** | 540 | 165 | 100 | 116 | 22 | 51 | 28 | 13 | **0.57** |
| **>90%** | 637 | 412 | 119 | 128 | 47 | 58 | 42 | 36 | **0.62** |

***Mean of four sampling days***

**Table 20: Shannon-Weaver index of diversity (H) for flower visitors during different weeks representing different per cent flowering during *Summer*-2015**

| Pollinators sp. / % flowering | *A. cerana* | *A. florea* | *T. iridipennis* | *Lasioglossum Sp* | *Ceratina sp.* | *Braunsapis sp.* | *Nomia sp.* | *I. scuttellaris* | "H" value |
|---|---|---|---|---|---|---|---|---|---|
| **25%** | 399 | 91 | 89 | 66 | 14 | 11 | 10 | 8 | **0.53** |
| **50%** | 476 | 138 | 90 | 98 | 17 | 28 | 16 | 10 | **0.58** |
| **75%** | 540 | 165 | 100 | 116 | 22 | 51 | 28 | 13 | **0.62** |
| **>90%** | 637 | 412 | 119 | 128 | 47 | 58 | 42 | 36 | **0.64** |

***Mean of four sampling days***

**Table 21: Berger-parker dominance index (d) for flower visitors during different weeks representing different per cent flowering during *Kharif*-2014**

| % flowering and "d" value / Pollinator sp. | 25 % Flower opening | 50 % Flower opening | 75 % Flower opening | >90 % Flower opening |
|---|---|---|---|---|
| | "d" value | "d" value | "d" value | "d" value |
| ***A. cerana*** | 0.58 | 0.55 | 0.52 | 0.43 |
| ***A. florea*** | 0.13 | 0.16 | 0.16 | 0.28 |
| ***T. iridipennis*** | 0.13 | 0.10 | 0.10 | 0.08 |
| ***Lasioglossum* sp.** | 0.10 | 0.11 | 0.11 | 0.09 |
| ***Ceratina* sp.** | 0.02 | 0.02 | 0.02 | 0.03 |
| ***Braunsapis* sp.** | 0.02 | 0.03 | 0.05 | 0.04 |
| ***Nomia* sp.** | 0.01 | 0.02 | 0.03 | 0.03 |
| ***I. scuttellaris*** | 0.01 | 0.01 | 0.01 | 0.02 |

***Mean of four sampling days***

**Table 22: Berger-parker dominance index (d) for flower visitors during different weeks representing different per cent flowering during *Rabi*-2014**

| % flowering and "d" value / Pollinator sp. | 25 % Flower opening | 50 % Flower opening | 75 % Flower opening | >90 % Flower opening |
|---|---|---|---|---|
| | "d" value | "d" value | "d" value | "d" value |
| ***A. cerana*** | 0.63 | 0.59 | 0.62 | 0.56 |
| ***A. florea*** | 0.17 | 0.17 | 0.12 | 0.12 |
| ***T. iridipennis*** | 0.04 | 0.05 | 0.08 | 0.10 |
| ***Lasioglossum* sp.** | 0.05 | 0.07 | 0.09 | 0.12 |
| ***Ceratina* sp.** | 0.03 | 0.03 | 0.02 | 0.02 |
| ***Braunsapis* sp.** | 0.04 | 0.04 | 0.03 | 0.04 |
| ***Nomia* sp.** | 0.03 | 0.03 | 0.02 | 0.02 |
| ***I. scuttellaris*** | 0.02 | 0.02 | 0.02 | 0.02 |

***Mean of four sampling days***

**Table 23: Berger-parker dominance index (d) for flower visitors during different weeks representing different per cent flowering in *Summer*-2015**

| % flowering and "d" value / Pollinator sp. | 25 % Flower opening | 50 % Flower opening | 75 % Flower opening | >90 % Flower opening |
|---|---|---|---|---|
| | "d" value | "d" value | "d" value | "d" value |
| ***A. cerana*** | 0.66 | 0.60 | 0.56 | 0.54 |
| ***A. florea*** | 0.14 | 0.16 | 0.14 | 0.13 |
| ***T. iridipennis*** | 0.06 | 0.08 | 0.10 | 0.10 |
| ***Lasioglossum* sp.** | 0.06 | 0.06 | 0.09 | 0.11 |
| ***Ceratina* sp.** | 0.03 | 0.03 | 0.03 | 0.04 |
| ***Braunsapis* sp.** | 0.02 | 0.02 | 0.03 | 0.03 |
| ***Nomia* sp.** | 0.02 | 0.02 | 0.02 | 0.02 |
| ***I. scuttellaris*** | 0.01 | 0.02 | 0.02 | 0.02 |

***Mean of four sampling days***

of flowers. The temporal variation in the production of the reward (nectar and pollen) also influences the rate of visitation. Differences in visitation rates among pollinators are probably related to both pollinator efficiency and effectiveness.

### 4.2.4 Correlation between floral abundance, weather parameters and pollinators activity during *kharif*-2014

The data on foraging activity of pollinators, *A. cerana, A. florea, T. irridipennis* and *Lasioglossum* sp. in bitter gourd, floral abundance and mean weather parameters *viz*., temperature, relative humidity, bright sunshine hours and rainfall during *kharif*-2014 were subjected to simple correlation analysis (Table 24).

The foraging activity of *A. cerana*, *A. florea*, *T. irridipennis* and *Lasioglossum* sp. during *kharif*-2014 in bitter gourd positively correlated with maximum temperature (r=0.610, r=0.611, r=0.755 and r=0.48, respectively), morning relative humidity ((r=0.062 for *A. cerana*), r=0.336 for *A. florea*) and (r=0.125 for *T. irridipennis*)) and rainfall ((r=0.820 for *A. cerana*), (r=0.934 for *T. irridipennis*) and (r=0.642 for *Lasioglossum* sp.)). However, pollinators *viz*., *A. cerana, A. florea, T. irridipennis* and *Lasioglossum* sp. were negatively influenced by minimum temperature (r=-0.314, r=-0.423, r=-0.226 and r=-0.299, respectively), evening relative humidity (r=-0.558, r=-0.317, r=-0.511 and r=-0.605, respectively) and bright sunshine hours (r=-0.653, r=-0.653, r=-0.515 and r=-0.667, respectively), whereas *Lasioglossum* sp. had negative association with morning relative humidity (r=-0.057) and positive correlation with floral abundance (r=0.848) .The influence of above factors was found to be non-significant with pollinator activity (Table 24).

*A. cerana* (r=0.951) and *T. irridipennis* (r=0.964) had significant positive correlation with floral abundance, while *A. florea*, had highly significant positive association with floral abundance (r=0.992) in addition to a significant association with rainfall (r= 0.977). The combined effect of the chosen weather parameters together might have influenced the foraging activity of all the above four pollinators.

When the data was subjected to linear regression analysis it revealed that, foraging activity of *A. cerana*, *A. florea, T. irridipennis* and *Lasioglossum* sp. was influenced by factors other than those chosen or it might be a combination of all the chosen weather parameters to an extent of 100 per cent ($R^2$=1.00) with the following linear regression equations, $Y= 882.80-8.80X_4-7.51X_6+0.14X_7$, $Y= 265.62-3.21X_4+8.17X_6+0.08X_7$, $Y=186.75-1.76X_4+1.05X_6$ and $Y=181.07-2.11X_4-4.99X_6+0.06X_7$ respectively (Table 24).

### 4.2.5 Correlation between floral abundance, weather parameters and pollinators activity during *rabi*-2014

The data on foraging activity of pollinators *A. cerana*, *A. florea*, *T. irridipennis* and *Lasioglossum* sp. in bitter gourd, floral abundance and mean weather parameters *viz*., temperature, relative humidity, bright sunshine hours and rainfall during *rabi*-2014 was subjected to simple correlation analysis (Table 25).

**Table 24: Correlation between weather parameters and pollinator activity in bitter gourd during *kharif*-2014**

| Weather parameters / Species | Temperature (°C) | | Relative humidity (%) | | Bright sunshine hours | Rainfall (mm) | Floral abundance | Regression Equation | $R^2$ Value |
|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Morning | Evening | | | | | |
| ***A. cerana*** | 0.610 | -0.314 | 0.062 | -0.558 | -0.653 | 0.820 | 0.951* | $Y= 882.80-8.80X_4-7.51X_6+0.14X_7$ | 1.00 |
| ***A. florea*** | 0.611 | -0.423 | 0.336 | -0.317 | -0.653 | 0.977* | 0.992** | $Y= 265.62-3.21X_4+8.17X_6+0.08X_7$ | 1.00 |
| ***T. irridipennis*** | 0.755 | -0.226 | 0.125 | -0.511 | -0.515 | 0.934 | 0.964* | $Y= 186.75-1.76X_4+1.05X_6$ | 1.00 |
| ***Lasioglossum* sp.** | 0.481 | -0.299 | -0.057 | -0.605 | -0.667 | 0.642 | 0.848 | $Y= 181.07-2.11X_4-4.99X_6+0.06X_7$ | 1.00 |

***** Correlation is significant at 0.01 level (2-tailed)* Correlation is significant at the 0.05 level (2-tailed)***

**Table 25: Correlation between weather parameters and pollinator activity in bitter gourd during *rabi*-2014**

| Weather parameters / Species | Temperature (°C) | | Relative humidity (%) | | Bright sunshine hours | Rainfall (mm) | Floral abundance | Regression Equation | $R^2$ Value |
|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Morning | Evening | | | | | |
| ***A. cerana*** | 0.741 | -0.936 | -0.970* | -0.999** | 0.987* | 0.0[a] | 0.930 | $Y= 2538.97-5.03X_2-45.91X_4+0.02X_7$ | 1.00 |
| ***A. florea*** | 0.689 | -0.958* | -0.970* | -0.884 | 0.862 | 0.0[a] | 0.884 | $Y= 7.86-19.53X_2+7.94X_4+0.02X_7$ | 1.00 |
| ***T. irridipennis*** | 0.905 | -0.804 | -0.937 | -0.941 | 0.987* | 0.0[a] | 0.985* | $Y= 292.68+10.27X_2-9.45X_4+0.03X_7$ | 1.00 |
| ***Lasioglossum* sp.** | 0.908 | -0.829 | -0.957* | -0.942 | 0.985* | 0.0[a] | 0.994** | $Y= 224.06+5.47X_2-6.25X_4+0.03X_7$ | 1.00 |

***** Correlation is significant at 0.01 level (2-tailed)* Correlation is significant at the 0.05 level (2-tailed)***

The foraging activity of *A. cerana, A. florea, T. irridipennis* and *Lasioglossum* sp. during *rabi*-2014 in bitter gourd was positively correlated with maximum temperature (r=0.741, r=0.689, r=0.905 and r=0.908, respectively) while, positive influence by bright sunshine hours against *A. florea* (0.862) and floral abundance against *A. cerana* (0.930) and *A. florea* (0.884). However, pollinators *viz*., *A. cerana, T. irridipennis* and *Lasioglossum* sp. were negatively influenced by minimum temperature (r=-0.936, r=-0.804 and r=-0.829, respectively) and evening relative humidity (r=-0.884, r=-0.941, and r=-0.942, respectively). The influence of above factors was found to be non-significant (Table 25).

The pollinators had significant negative correlation with weather parameters such as minimum temperature against *A. florea* (r=-0.958) and morning relative humidity against *A. cerana* (r=-0.970), *T. irridipennis* (r=-0.970) and *Lasioglossum* sp. (r=-0.957), while *A. cerana*, had highly significant association with evening relative humidity (r=0.999). There was significant and highly significant association with floral abundance against *T. irridipennis* (r=0.985) and *Lasioglossum* sp. (r=0.994), respectively during *rabi*-2104 in bitter gourd. However, rainfall, showed no relationship with any of the pollinators in bitter gourd. The combined effect of the chosen weather parameters together might have influenced the foraging activity of all the above four pollinators.

When the data was subjected to linear regression analysis it revealed that, foraging activity of *A. cerana, A. florea, T. irridipennis* and *Lasioglossum* sp. was influenced by factors other than those chosen or it might be a combination of all the chosen weather parameters to an extent of 100 per cent ($R^2$=1.00) with the following linear regression equations, $Y= 2538.97-5.03X_2-45.91X_4+0.02X_7$, $Y= 7.86-19.53X_2+ 7.94X_4+0.02X_7$, $Y= 292.68+10.27X_2-9.45X_4+0.03X_7$ and $Y= 224.06+5.47X_2-6.25X_4 +0.03X_7$ respectively (Table 25).

### 4.2.6 Correlation between floral abundance, weather parameters and pollinators activity in *summer*-2015

The correlation studies on foraging activity of pollinators *A. cerana, A. florea, T. irridipennis* and *Lasioglossum* sp. in bitter gourd, floral abundance and mean weather parameters *viz*., temperature, relative humidity, bright sunshine hours and rainfall during *summer*-2014 are presented below (Table 26).

The foraging activity of *A. cerana, A. florea, T. irridipennis* and *Lasioglossum* sp. during *summer*-2014 in bitter gourd was positively correlated with morning relative humidity (r=0.615, r=0.836, r=0.689 and 0.643, respectively), evening relative humidity (r=0.353, r=0.683, r=0.427 and r=0.323, respectively), bright sunshine hours (r=0.382, r=0.020, r=0.350 and r=0.510, respectively) and rainfall (r=0.908, r=0.840, r=0.869 and r=0.773, respectively) and negatively influenced by minimum temperature (r=-0.476, r=-0.779, r=-0.539 and r=-0.422, respectively). The maximum temperature showed positive association against *A. cerana* (r=0.053) and *Lasioglossum* sp. (r=0.143) while, negative association with *A. florea* (r=-0.336) and *T. irridipennis* (r=-0.005) whereas, floral abundance showed positive correlation with *Lasioglossum* sp. (r=0.925). The influence of above factors was found to be non-significant. The combined effect of the

**Table 26: Correlation between weather parameters and pollinator activity in bitter gourd during *summer*-2015**

| Species \ Weather parameters | Temperature (°C) | | Relative humidity (%) | | Bright sunshine hours | Rainfall (mm) | Floral abundance | Regression Equation | $R^2$ Value |
|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Morning | Evening | | | | | |
| ***A. cerana*** | 0.053 | -0.476 | 0.615 | 0.353 | 0.382 | 0.908 | 0.979* | Y= 732.57-7.55$X_4$-4.68 $X_6$+0.19$X_7$ | 1.00 |
| ***A. florea*** | -0.336 | -0.779 | 0.836 | 0.683 | 0.020 | 0.840 | 0.980* | Y= -7.34+1.83$X_4$+ 0.14$X_6$+0.03$X_7$ | 1.00 |
| ***T. irridipennis*** | -0.005 | -0.539 | 0.689 | 0.427 | 0.350 | 0.869 | 0.984* | Y= 141.80-2.30X4-3.12 $X_6$+0.07$X_7$ | 1.00 |
| ***Lasioglossum* sp.** | 0.143 | -0.422 | 0.643 | 0.323 | 0.510 | 0.773 | 0.925 | Y= 311.43-6.03$X_4$-9.09 $X_6$+0.13$X_7$ | 1.00 |

***** Correlation is significant at 0.01 level (2-tailed)* Correlation is significant at the 0.05 level (2-tailed)***

chosen weather parameters together might have influenced the foraging activity of all the above four pollinators. However, floral abundance showed significant positive association with pollinators *viz*., *A. cerana, A. florae* and *T. irridipennis* with the correlation value of r=0.979, r=0.980 and r=0.984, respectively (Table 26).

When the data was subjected to linear regression analysis it revealed that, foraging activity of *A. cerana*, *A. florea, T. irridipennis* and *Lasioglossum* sp. was influenced by factors other than those chosen or it might be a combination of all the chosen weather parameters to an extent of 100 per cent ($R^2$=1.00) with the following linear regression equations, $Y= 732.57-7.55X_4-4.68X_6+0.19X_7$, $Y= -7.34+1.83X_4+0.14X_6+0.03X_7$, $Y= 141.80-2.30X4-3.12X_6+0.07X_7$ and $Y= 311.43-6.03X_4-9.09X_6+0.13X_7$, respectively (Table 26).

The abundance of *Apis* species (*A. cerana* and *A. florea*) and non-*Apis* species (*T. irridipennis* and *Lasioglossum* sp.) were negatively correlated with minimum temperature and relative humidity in all three season. However, there was positive correlation of pollinator abundance with floral abundance. Hence, a minor variation in weather parameters like temperature, relative humidity, sunshine hours along with rainfall would not affect the activity of pollinators when there is availability of sufficient floral density for the pollinators to exploit both pollen and nectar as a reward during foraging.

### 4.3 Foraging behavior of efficient flower visitors

#### 4.3.1 Time of activity of the efficient pollinators

Activity of the two efficient pollinators *viz., A. cerana* and *A. florea* were found across different times of the day in bitter gourd. The activity of *A. cerana* started at 06.00h in the morning and continued till 17.00h. The peak abundance of *A. cerana* was between 08.00h to 09.00h, while it was between 10.00h-13.00h for *A. florea* in *kharif* and *rabi*-2014. In *summer*-2015, the peak activity of *A. cerana* and *A.florea* was between 07.00h-12.00h and 09.00-14.00h, respectively. Both *A. cerana* and *A. florea* were gradually dropped down after 15.00h (Table 27).

In the present study on bitter gourd, there was an “Intraspecific temporal resource partitioning” existing between two efficient pollinators *viz*., *A. cerana* and *A. florea*. Though the activity of these two species overlapped across different times of the day. *A. cerana* was more abundant in cooler hours of the day between 07.00-12.00h whereas, *A. florea* was abundant in hotter hours of the day between 09.00 – 14.00h. The non-*Apis* species were more active throughout the day from morning till evening.

#### 4.3.2 Number of visits to a single flower in a whole day and time lag between two subsequent visits

Staminate flowers received an average of 29.40 ± 1.51 bee visits per day, whereas pistillate flowers received 10.90 ± 1.45 bee visits per day. The average time between two

**Table 27: Time of activity of *A. cerana* and *A. florea* during *kharif*-2014, *rabi*-2014 and *summer*-2015**

| Season & Pollinator sp. / Time | *Kharif*-2014 | | *Rabi*-2014 | | *Summer*-2015 | |
|---|---|---|---|---|---|---|
| | *A. cerana* | *A. florea* | *A. cerana* | *A. florea* | *A. cerana* | *A. florea* |
| **06.00-07.00h** | 32 | 0 | 23 | 0 | 30 | 0 |
| **07.00-08.00h** | 92 | 4 | 66 | 1 | 70 | 1 |
| **08.00-09.00h** | 112 | 15 | 77 | 3 | 83 | 9 |
| **09.00-10.00h** | 87 | 25 | 65 | 7 | 90 | 13 |
| **10.00-11.00h** | 70 | 38 | 46 | 15 | 74 | 22 |
| **11.00-12.00h** | 57 | 38 | 37 | 19 | 55 | 26 |
| **12.00-13.00h** | 28 | 38 | 21 | 18 | 39 | 19 |
| **13.00-14.00h** | 17 | 24 | 11 | 10 | 13 | 12 |
| **14.00-15.00h** | 11 | 14 | 10 | 7 | 8 | 8 |
| **15.00-16.00h** | 6 | 5 | 5 | 2 | 7 | 3 |
| **16.00-17.00h** | 2 | 1 | 2 | 2 | 3 | 2 |
| **17.00-18.00h** | 0 | 0 | 1 | 0 | 1 | 0 |
| **18.00-19.00h** | 0 | 0 | 0 | 0 | 0 | 1 |
| **Mean ± SD** | **39.46±39.30** | **15.5±15.6** | **27.98±27.36** | **6.40±7.01** | **36.23±34.10** | **8.79±8.92** |

subsequent visits for staminate flowers was 16.40 ± 0.36 minutes, while it was 41.31 ± 0.93 minutes for pistillate flowers (Table 28).

Similarly, Mc Gregor *et al.* (1965) observed that honey bee visit to each flower about every 15 minutes is desirable for maximum fruit set in Cantaloupe. They calculated that one bee for every 10 hermaphrodite flowers was necessary to provide this rate of visitation. The variations in visits by honey bees may occur between plants sometimes only a few feet apart, if there is a variation in the microclimate around the plants. This means, many flowers might receive more visits than necessary, if all are to receive the optimum number (Whitaker and Bohn, 1952). The present results are in agreement with Revanasidda (2015), who opined that staminate and hermaphrodite flowers of muskmelon received bee visits once every 19.03 and 38.24 minutes, respectively. Each staminate and hermaphrodite flower in muskmelon crop received an average 46.6 and 17.2 visits/day respectively. In the present study, the average time between two subsequent visits for staminate and pistillate flowers was 16.40 and 41.31minutes, respectively. Each staminate and hermaphrodite flower receives an average of 29.40 and 10.90 visits/day, respectively. The higher ratio of staminate flowers is an evolutionary advantage to the plant in the form of higher density and diversity of pollen deposited on stigma of pistillate flowers.

### 4.3.3 Number of flowers visited per unit time per trip

The mean total time taken per trip by *A. cerana* was 109.10 ± 9.96 min and the number of flowers visited during this time was 310.61 ± 31.07, which was significantly higher than that by *A. florea i.e.*, the mean total time taken per trip by *A. florea* was 85.37 ± 11.25 min to visit 131.57 ± 11.95 flowers were visited (Table 29 and Fig. 17).

The present findings are in conformity with Revanasidda (2015), who opined that *A. cerana* visited significantly more number flowers (398 ± 38.51) and travelled greater distance (63 ± 7.82 m) by taking less time (121 ± 15 min per trip) compared to *A. florea* which visited lesser number of flowers (281 ± 20.79), travelled less distance (36 ± 5.94 m) by taking more time (109 ± 17.85 min per trip) in musk melon. Mann (1953) recorded that perfect flowers of cantaloupe were visited by honeybees at an average of 53 times and 42 times for staminate flowers. In the present study, more number of flowers were visited by *A. cerana* compared to *A. florea*. This is mainly because of rapid flight and less time spent per flower by *A. cerana* compared to *A. florea* which had slow flight behaviour and spent more time per flower. This would hint towards *A. cerana*, being more efficient of the two pollinators.

### 4.3.4 Pollen efficiency index and pollen removal index

In bitter gourd, *A. cerana* and *A. florea* were more frequent visitors compared to other species. Among these, *A. cerana* foragers were found to be more efficient pollinators of bitter gourd (pollen removal index= 0.81 and pollination efficiency index= 0.22) compared to *A. florea* (pollen removal index= 0.37 and pollination efficiency index= 0.13) (Table 30 and 31). *Apis* sp. are prime pollinators as they are capable of carrying pollen and in the process, the plants visited by them are benefited by diverse amount of pollens (Fig. 18).

**Table 28: Number of visits by pollinators to a single flower for whole day and time between two subsequent visits (n=10 flowers)**

| Parameters / Flower No. | No. visits received per day | | Average time between two subsequent visits | |
|---|---|---|---|---|
| | **Staminate flower** | **Pistillate flower** | **Staminate flower** | **Pistillate flower** |
| **1** | 27 | 10 | 16.30 | 42.60 |
| **2** | 28 | 11 | 16.54 | 41.91 |
| **3** | 32 | 12 | 16.28 | 42.58 |
| **4** | 29 | 12 | 16.86 | 41.17 |
| **5** | 30 | 8 | 17.17 | 41.38 |
| **6** | 31 | 12 | 16.32 | 40.08 |
| **7** | 30 | 11 | 16.10 | 41.73 |
| **8** | 30 | 9 | 16.17 | 41.22 |
| **9** | 28 | 12 | 16.11 | 40.08 |
| **10** | 29 | 12 | 16.14 | 40.33 |
| **Mean ± SD** | **29.40 ± 1.51** | **10.90 ± 1.45** | **16.40 ± 0.36** | **41.31 ± 0.93** |

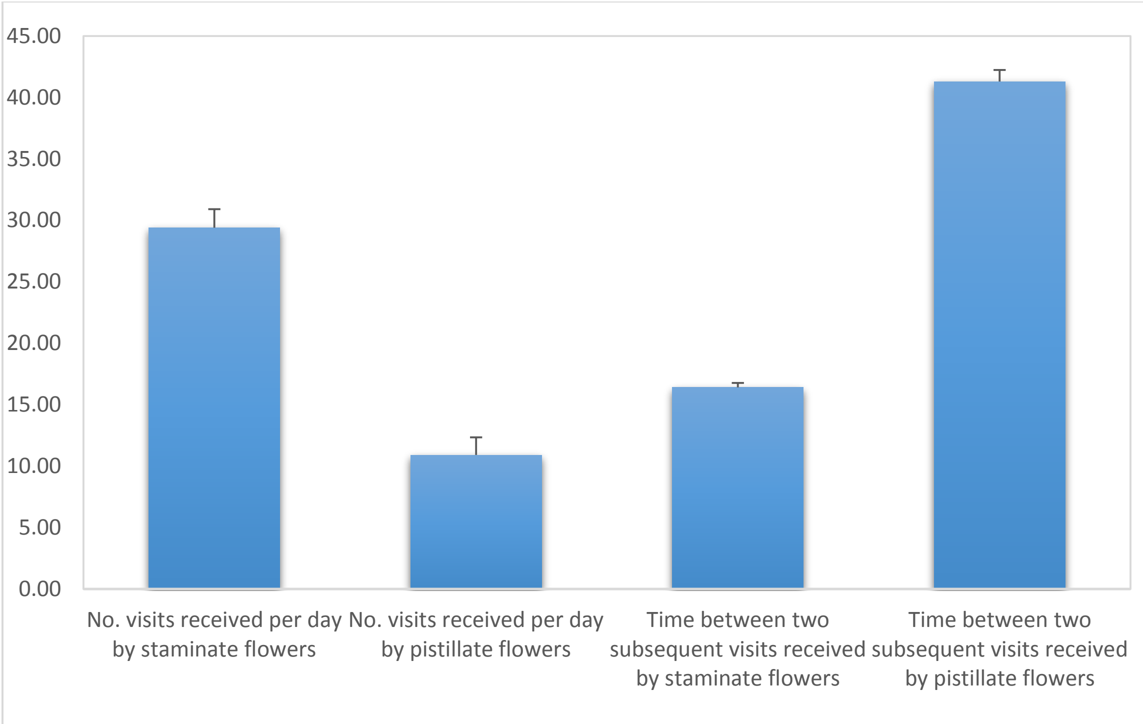


**Fig. 17: Mean number of visits received per day and time between two subsequent visit to staminate and pistillate flowers of bitter gourd**

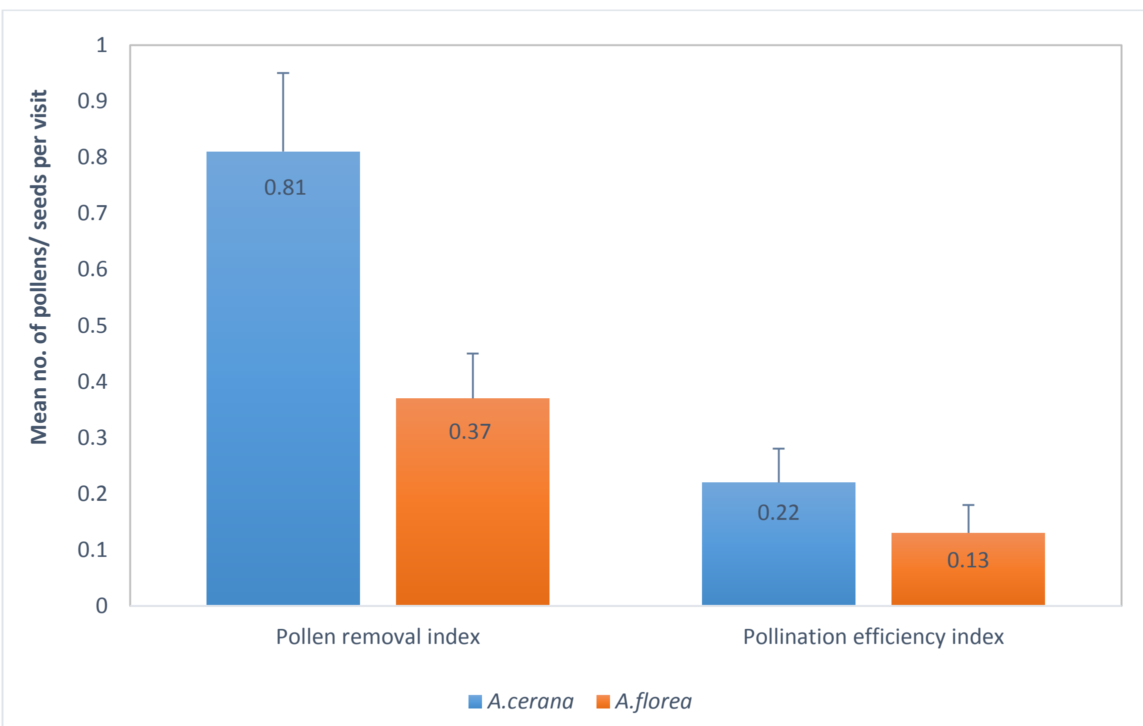


**Fig. 18: Pollen removal index and pollination efficiency index of *A. cerana* and *A. florea***

**Table 29: Number of flowers visited per unit time per trip by *A. cerana* and *A. florea* (n= 30 bees)**

| Parameters / Bee No. | Total time taken for a trip (min) | | No. of flower visited | |
|---|---|---|---|---|
| | ***A. cerana*** | ***A. florea*** | ***A. cerana*** | ***A. florea*** |
| **1** | 111.83 | 73.01 | 343 | 136 |
| **2** | 98.33 | 79.45 | 314 | 127 |
| **3** | 99.26 | 70.91 | 302 | 154 |
| **4** | 113.56 | 54.29 | 354 | 127 |
| **5** | 82.55 | 86.05 | 278 | 141 |
| **6** | 100.83 | 72.74 | 285 | 137 |
| **7** | 118.33 | 56.88 | 274 | 148 |
| **8** | 94.67 | 80.07 | 295 | 124 |
| **9** | 126.83 | 88.07 | 278 | 133 |
| **10** | 110.00 | 96.80 | 282 | 123 |
| **11** | 113.60 | 82.80 | 295 | 135 |
| **12** | 108.00 | 84.39 | 362 | 131 |
| **13** | 98.40 | 88.40 | 330 | 124 |
| **14** | 112.80 | 85.57 | 362 | 138 |
| **15** | 116.00 | 102.17 | 290 | 142 |
| **16** | 130.40 | 83.07 | 317 | 113 |
| **17** | 104.80 | 88.43 | 292 | 131 |
| **18** | 118.40 | 90.40 | 285 | 150 |
| **19** | 101.60 | 85.75 | 279 | 144 |
| **20** | 110.40 | 97.53 | 311 | 140 |
| **21** | 103.20 | 101.53 | 337 | 145 |
| **22** | 116.00 | 83.75 | 332 | 106 |
| **23** | 121.60 | 88.37 | 342 | 118 |
| **24** | 108.00 | 94.69 | 342 | 109 |
| **25** | 107.20 | 84.21 | 289 | 146 |
| **26** | 106.40 | 90.17 | 300 | 124 |
| **27** | 112.00 | 97.08 | 250 | 137 |
| **28** | 115.20 | 88.82 | 295 | 126 |
| **29** | 114.40 | 97.09 | 362 | 121 |
| **30** | 98.40 | 88.65 | 343 | 126 |
| **Mean ± SD** | **109.10 ± 9.96** | **85.37 ± 11.25** | **310.61 ± 31.07** | **131.57 ± 11.95** |
| **T test** | **8.72**** | | **25.98**** | |

***T - critical value 1.699, ** Significant at 0.01 level***

**Table 30: Pollen removal efficiency and pollination efficiency index in *A. cerana* (n= 20 flowers)**

| Flower No. | Pollen Removal Efficiency | | | | | Pollination Efficiency Index | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. of pollen grains with no visit | No. of Pollens after one visit | No. of Pollens in unrestricted visits | No of pollens removed in unrestricted visit | Pollen removal efficiency | No pollens deposited upon single visit | No of seeds in a fruit received single visit | No of seeds with no visits | No of seeds in unrestricted visits | Pollination efficiency index |
| **1** | 9645 | 6100 | 845 | 8800 | 0.69 | 745 | 8 | 0 | 32 | 0.25 |
| **2** | 9475 | 6548 | 745 | 8730 | 0.75 | 652 | 6 | 0 | 26 | 0.23 |
| **3** | 9600 | 5234 | 658 | 8942 | 0.59 | 684 | 4 | 0 | 33 | 0.12 |
| **4** | 8456 | 7561 | 784 | 7672 | 0.99 | 865 | 9 | 0 | 26 | 0.35 |
| **5** | 9600 | 7520 | 842 | 8758 | 0.86 | 523 | 6 | 0 | 28 | 0.21 |
| **6** | 8546 | 5694 | 845 | 7701 | 0.74 | 625 | 5 | 0 | 27 | 0.19 |
| **7** | 9325 | 6524 | 741 | 8584 | 0.76 | 745 | 8 | 0 | 30 | 0.27 |
| **8** | 9586 | 5472 | 725 | 8861 | 0.62 | 523 | 7 | 0 | 31 | 0.23 |
| **9** | 9568 | 6520 | 659 | 8909 | 0.73 | 235 | 6 | 0 | 29 | 0.21 |
| **10** | 9654 | 8563 | 765 | 8889 | 0.96 | 625 | 3 | 0 | 34 | 0.09 |
| **11** | 9563 | 7530 | 785 | 8778 | 0.86 | 745 | 6 | 0 | 22 | 0.27 |
| **12** | 8654 | 6523 | 845 | 7809 | 0.84 | 523 | 5 | 0 | 21 | 0.24 |
| **13** | 8514 | 8541 | 865 | 7649 | 1.12 | 625 | 3 | 0 | 30 | 0.1 |
| **14** | 9600 | 8523 | 654 | 8946 | 0.95 | 745 | 8 | 0 | 32 | 0.25 |
| **15** | 9600 | 8541 | 874 | 8726 | 0.98 | 523 | 7 | 0 | 26 | 0.27 |
| **16** | 9325 | 6582 | 841 | 8484 | 0.78 | 745 | 6 | 0 | 21 | 0.29 |
| **17** | 8564 | 5426 | 658 | 7906 | 0.69 | 596 | 8 | 0 | 28 | 0.29 |
| **18** | 8514 | 5426 | 652 | 7862 | 0.69 | 412 | 5 | 0 | 24 | 0.21 |
| **19** | 7542 | 6854 | 632 | 6910 | 0.99 | 423 | 5 | 0 | 22 | 0.23 |
| **20** | 9652 | 6548 | 654 | 8998 | 0.73 | 625 | 4 | 0 | 21 | 0.19 |
| **Mean±SD** | 9149.15± 611.03 | 6811.50± 1121.1 | 753.45± 86.66 | 8395.70± 608.38 | **0.81± 0.14** | 609.20± 146.82 | 5.95± 1.73 | 0.00±0 | 27.15± 4.26 | **0.22± 0.06** |

**Table 31: Pollen removal efficiency and pollination efficiency index in *A. florea* (n= 20 flowers)**

| Flower No. | Pollen Removal Efficiency | | | | | Pollination Efficiency Index | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. of pollen grains with no visit | No. of Pollens after one visit | No. of Pollens in unrestricted visits | No of pollens removed in unrestricted visit | Pollen removal efficiency | No pollens deposited upon single visit | No of seeds in a fruit received single visit | No of seeds with no visits | No of seeds in unrestricted visits | Pollination efficiency index |
| **1** | 9645 | 4214 | 845 | 8800 | 0.48 | 124 | 2 | 0 | 32 | 0.06 |
| **2** | 9475 | 3524 | 745 | 8730 | 0.4 | 235 | 3 | 0 | 26 | 0.12 |
| **3** | 9600 | 3684 | 658 | 8942 | 0.41 | 214 | 4 | 0 | 33 | 0.12 |
| **4** | 8456 | 3256 | 784 | 7672 | 0.42 | 158 | 2 | 0 | 26 | 0.08 |
| **5** | 9600 | 4125 | 842 | 8758 | 0.47 | 264 | 3 | 0 | 28 | 0.11 |
| **6** | 8546 | 2145 | 845 | 7701 | 0.28 | 248 | 4 | 0 | 27 | 0.15 |
| **7** | 9325 | 2658 | 741 | 8584 | 0.31 | 159 | 5 | 0 | 30 | 0.17 |
| **8** | 9586 | 3254 | 725 | 8861 | 0.37 | 136 | 2 | 0 | 31 | 0.06 |
| **9** | 9568 | 2369 | 659 | 8909 | 0.27 | 125 | 3 | 0 | 29 | 0.1 |
| **10** | 9654 | 4536 | 765 | 8889 | 0.51 | 186 | 4 | 0 | 34 | 0.12 |
| **11** | 9563 | 2356 | 785 | 8778 | 0.27 | 142 | 2 | 0 | 22 | 0.09 |
| **12** | 8654 | 2586 | 845 | 7809 | 0.33 | 156 | 2 | 0 | 21 | 0.1 |
| **13** | 8514 | 2145 | 865 | 7649 | 0.28 | 214 | 3 | 0 | 30 | 0.1 |
| **14** | 9600 | 2153 | 654 | 8946 | 0.24 | 259 | 4 | 0 | 32 | 0.13 |
| **15** | 9600 | 2548 | 874 | 8726 | 0.29 | 264 | 2 | 0 | 26 | 0.08 |
| **16** | 9325 | 3625 | 841 | 8484 | 0.43 | 245 | 3 | 0 | 21 | 0.14 |
| **17** | 8564 | 3256 | 658 | 7906 | 0.41 | 236 | 4 | 0 | 28 | 0.14 |
| **18** | 8514 | 3258 | 652 | 7862 | 0.41 | 263 | 5 | 0 | 24 | 0.21 |
| **19** | 7542 | 3256 | 632 | 6910 | 0.47 | 248 | 5 | 0 | 22 | 0.23 |
| **20** | 9652 | 3256 | 654 | 8998 | 0.36 | 269 | 4 | 0 | 21 | 0.19 |
| **Mean ± SD** | 9149.15± 611.03 | 3110.20± 720.64 | 753.45± 86.66 | 8395.70± 608.38 | **0.37± 0.08** | 207.25± 52.98 | 3.30± 1.08 | 0.00±0 | 27.15± 4.26 | **0.12± 0.05** |

### 4.3.5 Movement pattern

The overall ratio of staminate to pistillate flowers ranged from 18:1 to 20:1. The ratio of visits to staminate and pistillate flowers by *A. cerana* and *A. florea* were 11:1 and 9:1, respectively (Table 32). In a single trip, the two species of bees (*A. cerana* and *A. florea*) visited a total of 310 ± 31.07 and 131 ± 11.94 flowers, respectively covering a distance of 72.00 ± 6.57m and 53 ± 6.97m, respectively. The time taken by the two species of bees was found to be 109±9.96 and 85±11.24 min, respectively (Table 33).

Leonie *et al.* (2009) also reported that pollinator flight distances in muskmelon field varied from 25 to 69 cm. Similarly, Revanasidda (2015) revealed that least and maximum number of staminate flowers visited by *A. cerana* and *A. florea* before visiting a hermaphrodite flower were 5.4 and 9.75 and 4.75 and 9.66, respectively. As the sex ratio of the flowers is male-biased, this would mean greater number of male flowers was visited and hence, greater diversity of pollen collected by the bees. This would hint towards *A. cerana* being more efficient of the two pollinators. Movement pattern revealed that both *A. florea* tend to spread across the field while that of *A. cerana* tend to be patchy and move horizontally, which may influence their pollination efficiencies (Fig. 19, 20, 21 and 22).

### 4.3.6 Time spent per flower

On both staminate and pistillate flowers, the time spent per flower by *A. cerana* (23.45 ± 8.53 and 2.04 ± 0.65, respectively; t-test=25.03, $p \leq 0.01$) was more than the time spent per flower by *A. florea* (6.50 ± 0.8 and 1.11 ± 0.15, respectively; t-test= 54.56, $p \leq 0.01$). Both *A. cerana* and *A. florea* spent less time on pistillate flowers (2.04 ± 0.65 and 1.11 ± 0.15, respectively; t-test=19.74, $p \leq 0.01$) when compared to that on staminate flowers (23.45 ± 8.53 and 6.50 ± 0.8, respectively; t-test=13.92, $p \leq 0.01$) (Table 34).

In the present study, both *A. cerana* (1.5 times) and *A. florea* (1.3 times) spent more time on staminate flowers as compared to pistillate flowers. This is mainly due to rewards like pollen grains and nectaries in staminate flowers. In contrast, Mann (1953) opined that bees remained 1.5 times as long on perfect flowers compared to staminate flowers. The open position of the bitter gourd flowers makes them easy for the pollinators to access and exploit floral rewards. The flat structure of the flower is ideal for easy landing of pollinators and also enhances the variety of floral visitors. In pistillate flowers, yellow colour and scent serve as attractants for flower visitors for more pollen deposition. The overall ratio of staminate to pistillate flowers was very high ranging from 18:1 to 20:1, but the ratio of visits to staminate and pistillate flowers by *A. cerana* and *A. florea* was 11:1 and 9:1, respectively (Fig. 23).

### 4.3.7 Reward collection by efficient foraging species

In bitter gourd ecosystem, it was observed that both *A. cerana* and *A. florea* tend to collect both pollen and nectar in a foraging trip. *A. cerana* makes normally 4-5 trips per day (3 to 4 trips from 06.00h to 12.00 h and 1 trip in the afternoon from 14.00h to 17.00 h), whereas *A. florea* makes 2-3 (rarely 4) trips per day from 07.00 h to 17.00 h.

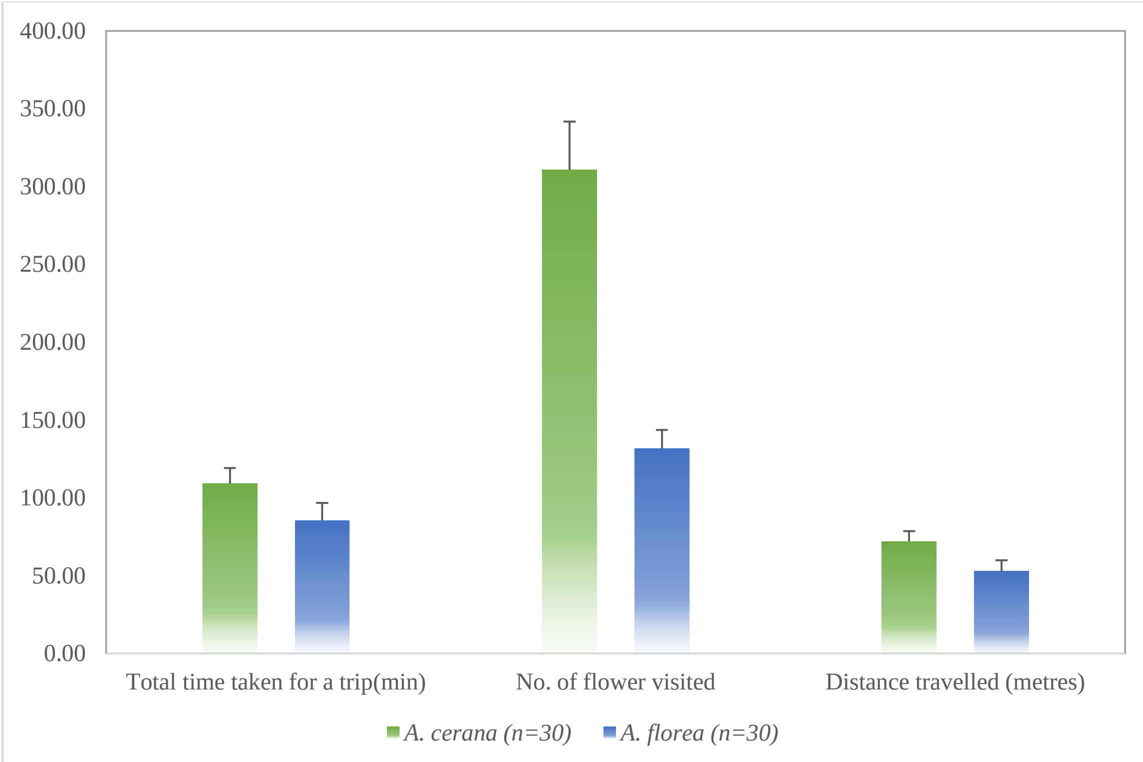


**Fig. 19: Movement pattern of two species of bees in whole bitter gourd plot**

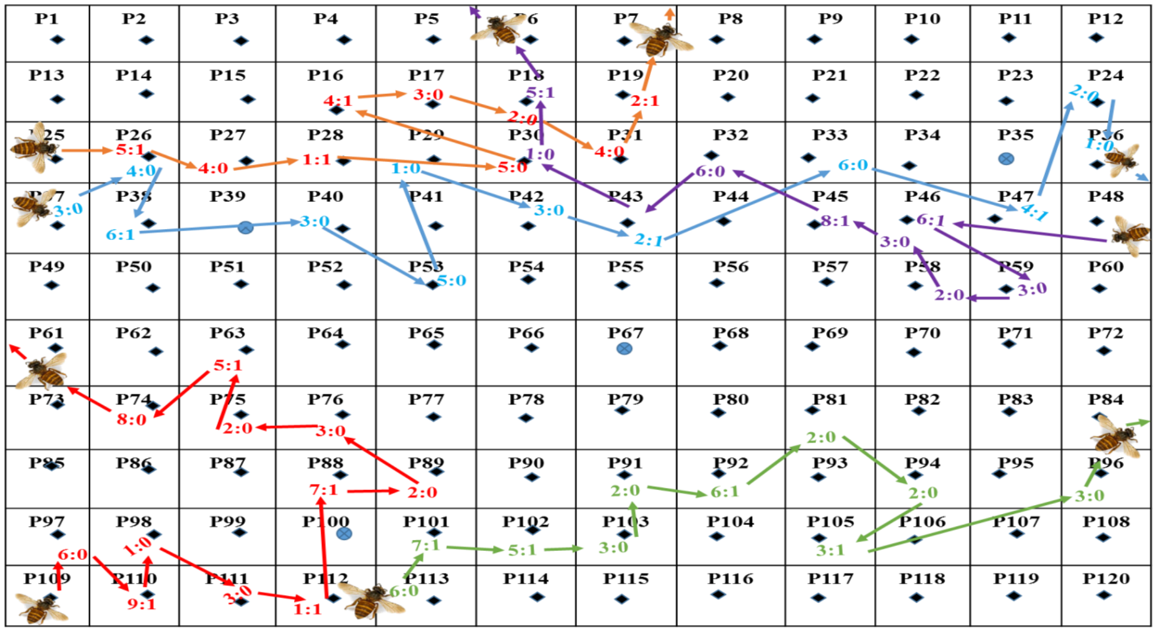

**Fig. 20: Movement pattern of *A. cerana* (n=5) in selected patch of experimental plot**

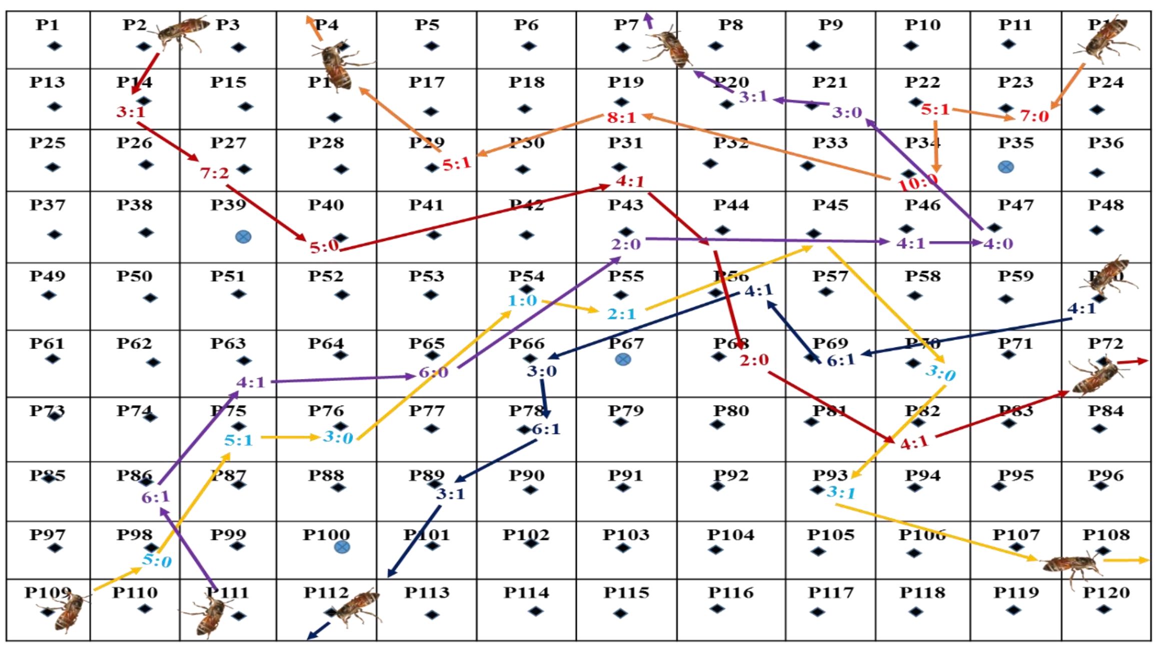

**Fig. 21: Movement pattern of *A. florea* (n=5) in selected patch of experimental plot**

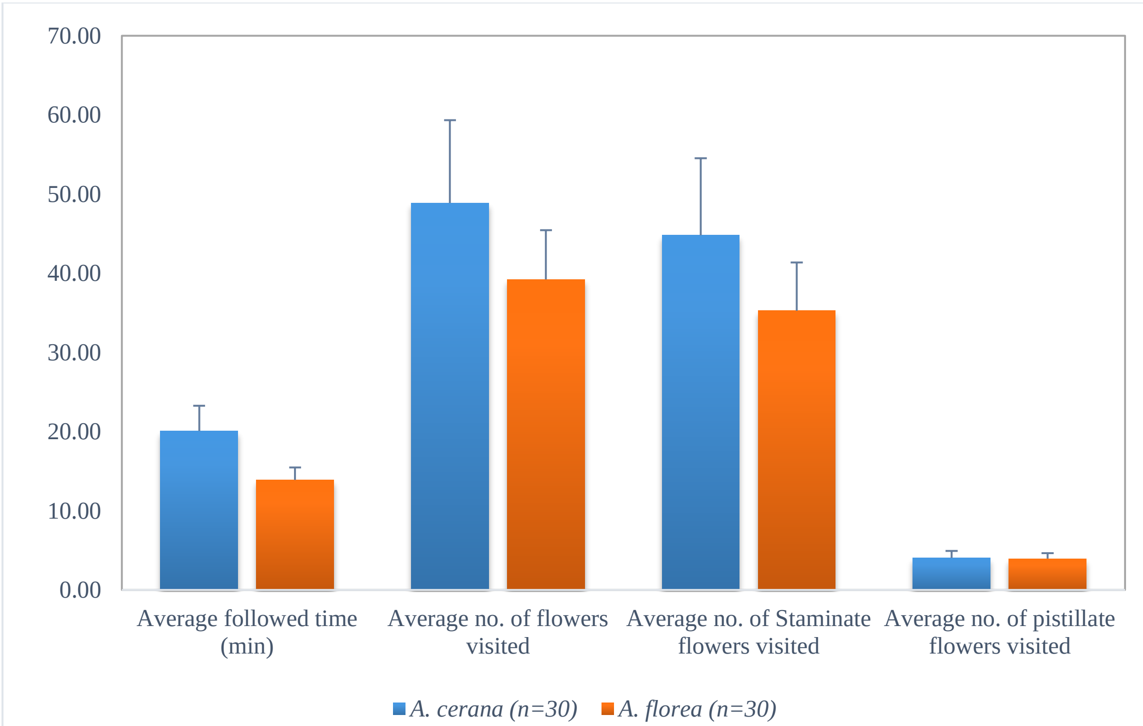


**Fig. 22: Ratio of visits by efficient foraging bees to different sexes of flowers**

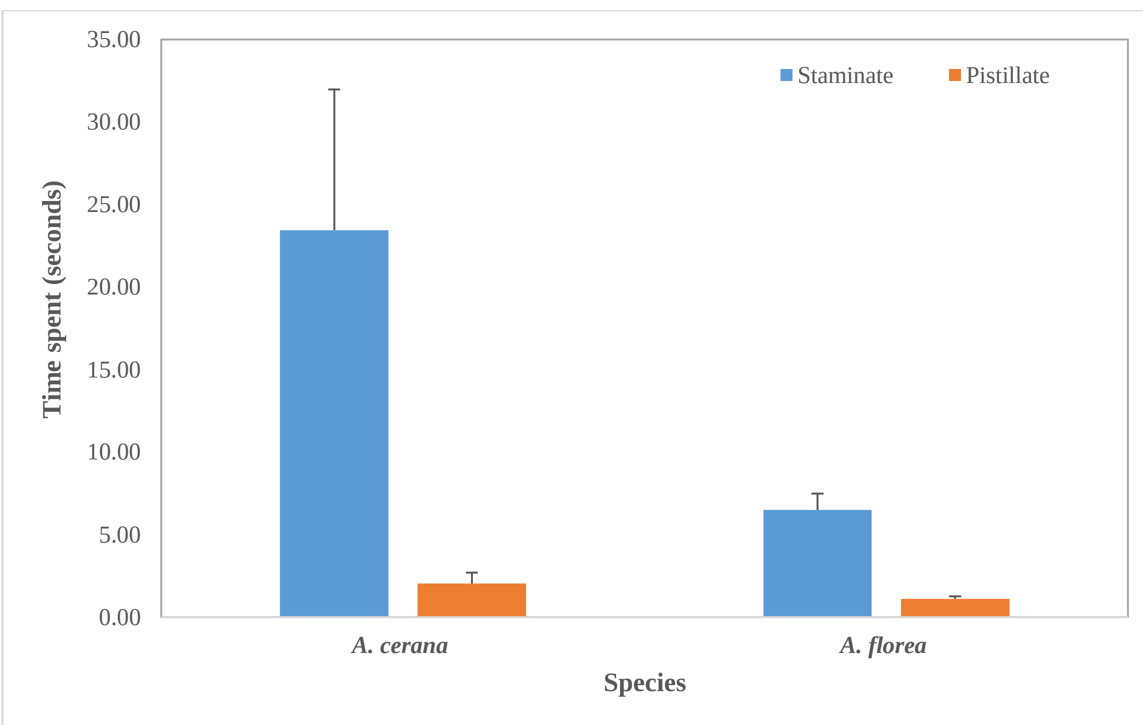


**Fig. 23: Mean time spent per flower by the two species of bees on two types of bitter gourd flowers**

**Table 32: Movement pattern of honey bees in bitter gourd to work out the ratio of visits to staminate and pistillate flowers**

| Sl. No. | *A. cerana* (n= 30) | | | | | *A. florea* (n= 30) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time monitored (min) | Total No. of flowers visited | No. of staminate flower visited | No. of pistillate flower visited | Ratio | Time monitored (min) | Total No. of flowers visited | No. of staminate flower visited | No. of pistillate flower visited | Ratio |
| **1** | 20.18 | 51 | 47 | 4 | 11.75 | 14.40 | 36 | 32 | 4 | 8.00 |
| **2** | 20.93 | 42 | 38 | 4 | 9.50 | 15.90 | 25 | 22 | 3 | 7.33 |
| **3** | 16.42 | 43 | 40 | 3 | 13.33 | 14.27 | 38 | 35 | 3 | 11.67 |
| **4** | 18.75 | 37 | 34 | 3 | 11.33 | 18.70 | 31 | 26 | 5 | 5.20 |
| **5** | 14.22 | 34 | 30 | 4 | 7.50 | 14.02 | 29 | 25 | 4 | 6.25 |
| **6** | 18.37 | 48 | 44 | 4 | 11.00 | 14.42 | 35 | 32 | 3 | 10.67 |
| **7** | 23.72 | 62 | 57 | 5 | 11.40 | 12.42 | 38 | 34 | 4 | 8.50 |
| **8** | 25.57 | 58 | 53 | 5 | 10.60 | 13.15 | 43 | 39 | 4 | 9.75 |
| **9** | 20.00 | 52 | 47 | 5 | 9.40 | 12.55 | 45 | 41 | 4 | 10.25 |
| **10** | 24.27 | 63 | 57 | 6 | 9.50 | 16.05 | 41 | 36 | 5 | 7.20 |
| **11** | 20.58 | 52 | 48 | 4 | 12.00 | 14.20 | 41 | 37 | 4 | 9.25 |
| **12** | 16.42 | 66 | 61 | 5 | 12.20 | 13.08 | 46 | 42 | 4 | 10.50 |
| **13** | 14.27 | 32 | 29 | 3 | 9.67 | 16.03 | 39 | 35 | 4 | 8.75 |
| **14** | 24.30 | 34 | 31 | 3 | 10.33 | 12.60 | 36 | 32 | 4 | 8.00 |
| **15** | 23.77 | 51 | 47 | 4 | 11.75 | 14.57 | 35 | 29 | 6 | 4.83 |
| **16** | 23.75 | 46 | 42 | 4 | 10.50 | 12.52 | 28 | 25 | 3 | 8.33 |
| **17** | 20.58 | 54 | 49 | 5 | 9.80 | 12.42 | 51 | 46 | 5 | 9.20 |
| **18** | 18.93 | 42 | 39 | 3 | 13.00 | 14.22 | 42 | 38 | 4 | 9.50 |
| **19** | 18.75 | 31 | 28 | 3 | 9.33 | 16.08 | 38 | 34 | 4 | 8.50 |
| **20** | 24.20 | 33 | 30 | 3 | 10.00 | 14.37 | 43 | 39 | 4 | 9.75 |
| **21** | 20.60 | 36 | 33 | 3 | 11.00 | 12.70 | 36 | 32 | 4 | 8.00 |
| **22** | 20.75 | 59 | 54 | 5 | 10.80 | 15.75 | 47 | 43 | 4 | 10.75 |
| **23** | 22.53 | 68 | 62 | 6 | 10.33 | 14.03 | 52 | 48 | 4 | 12.00 |
| **24** | 18.38 | 54 | 50 | 4 | 12.50 | 12.38 | 44 | 41 | 3 | 13.67 |
| **25** | 20.07 | 58 | 54 | 4 | 13.50 | 13.10 | 43 | 39 | 4 | 9.75 |
| **26** | 16.08 | 52 | 48 | 4 | 12.00 | 12.53 | 39 | 35 | 4 | 8.75 |
| **27** | 14.23 | 54 | 50 | 4 | 12.50 | 12.43 | 42 | 38 | 4 | 9.50 |
| **28** | 22.70 | 51 | 47 | 4 | 11.75 | 11.92 | 40 | 36 | 4 | 9.00 |
| **29** | 20.07 | 53 | 49 | 4 | 12.25 | 12.42 | 38 | 34 | 4 | 8.50 |
| **30** | 18.87 | 50 | 46 | 4 | 11.50 | 14.30 | 36 | 33 | 3 | 11.00 |
| **Mean±SD** | **20.08±10.48** | **48.87±9.74** | **44.80±0.87** | **4.07±1.38** | **11.07±1.57** | **13.92±6.20** | **39.23±6.09** | **35.27±0.67** | **3.97±1.89** | **9.08±3.19** |
| **Range** | **14.22-24.30** | **31-68** | **28-62** | **3-6** | **7.50-13.50** | **11.92-16.08** | **25-52** | **22-48** | **3-6** | **4.83-13.67** |

**Table 33: Distance travelled per foraging trip by *A. cerana* and *A. florea***

| Parameters | *A. cerana* (n=30) | *A. florea* (n=30) |
|---|---|---|
| **Time monitored (min)** | 109±9.96 | 85±11.24 |
| **No. of flowers visited** | 310±31.07 | 131±11.94 |
| **Distance travelled (m)** | 72.00±6.57 | 53±6.97 |

**Table 34: Mean time spent per flower by *A. cerana* and *A. florea* on staminate and pistillate flowers (n=100 flowers)**

| **Species** | ***A. cerana*** | | ***A. florea*** | |
|---|---|---|---|---|
| **Flower type** | **Staminate** | **Pistillate** | **Staminate** | **Pistillate** |
| **Mean time spent (sec)** | 23.45 ± 8.53 | 2.04 ± 0.65 | 6.50 ± 0.8 | 1.11 ± 0.15 |
| **z-test** | **25.03**** | | **54.56**** | |
| **Flower type** | **Staminate** | | **Pistillate** | |
| **Species** | ***A. cerana*** | ***A. florea*** | ***A. cerana*** | ***A. florea*** |
| **Mean time spent (sec)** | 23.45 ± 8.53 | 6.50 ± 0.8 | 2.04 ± 0.65 | 1.11 ± 0.15 |
| **z-test** | **19.74**** | | **13.92**** | |

***z - critical value 1.96, ** -Significant at 0.01 level***

During morning hours, foragers of both the species collected pollen or nectar while in the afternoon when pollen was exhausted from the flowers, most of the pollen collectors turned into nectar gatherers as nectar production by flowers was continuous throughout the day.

Staminate flowers offered rewards (nectar and pollen) for flower visitors, while the pistillate flowers were rewardless. Similar observations were recorded in other members of Cucurbitaceae like *Momordica* sp., *Lagenaria* spp., *Luffa* spp., (Bahadur *et al.*, 1986) and in *M. charantia* (Mary *et al.*, 2012). Staminate flower mimicry by pistillate flowers was evident in this study. Mimicry of staminate flowers by the rewardless pistillate flowers have been reported in a number of plant species including, *Carica papaya* (Baker, 1976), *Ecballium elaterium* (Dukas, 1987), *Begonia* sp. (Schemske *et al.* 1996) and *M. charantia* (Lenzi *et al*. 2005; Deyto and Cervancia, 2009). From this study, it is believed that the higher number of staminate flowers and the resemblance of pistillate flowers enhance the chances of visiting pistillate flowers by efficient pollinators, resulting in high fruit and seed set.

Regarding reward collection by foragers in bitter gourd, both the species are efficient pollinators and collect both pollen and nectar during same time. From afternoon onwards part of pollen foragers turned into nectar foragers as pollen density in field decreased in flowers from late noon (Plate 24 and 25).

### 4.4 Role of flower visitors in pollination and fruit set

The results of pollinator exclusion experiments conducted to assess the role of flower visitors on pollination and fruit set in muskmelon are presented below.

#### 4.4.1 Controlled visit experiments (No. of visits/flower/day and yield parameters) (n=30 flowers)

The results of the controlled visits experiment showed that, the bitter gourd crop requires 15-20 bee visits/flower to produce maximum yield parameters, apart from number of fruits set. There was also increase in yield parameters like mean weight, size and number of seeds per fruit upon increase in number of visits/flower (Table 35). Yield parameters like number of fruits set (% fruit set), length, weight and number of seeds were found to be zero at 0 visits/flower. There was no fruit set in watermelon plots excluded from insect pollinators, as in the current study (Mohan Rao and Suryanarayana, 1988) (Plate 29). Similarly, the yields of muskmelon fruits were higher in plants pollinated by bees, and plants in which bees were excluded set practically no fruits, opined by Kauffeld and Williams (1972); Kauffeld *et al.* (1975); Mohan Rao and Suryanarayana (1988) in watermelon; Deyto and Cervancia (2009) and Mary *et al.* (2012) in bitter gourd. If there is no pollination or transfer of pollen from staminate to sigma of pistillate flower, the flower aborts, dries up and withers off from the plant. The fruit number and fruit weight were higher in honey bee pollinated crop than that in open pollination in watermelon (Rao and Suryanarayana, 1988).

The other reports on pumpkin crop revealed that flowers that were bagged to exclude bee visits and exposed to different numbers of bee visits showed a fruit set of 6.5

**Table 35: Relationship between number of visits/ pistillate flowers and yield (n=30 flowers each)**

| Yield parameters / No. of visits | No. of fruits set | % fruit set | Mean length of the fruit (cm) | Mean weight of the fruit (g) | Mean No. of seeds |
|---|---|---|---|---|---|
| **0 visit** | 0 | 0 | 0 | 0 | 0 |
| **1 visit** | 3 | 10 | 0.60±1.77 | 2.1±6.41 | 0.2±0.53 |
| **2 visits** | 5 | 16 | 0.93±2.41 | 3.03±7.89 | 0.5±1.33 |
| **5 visits** | 8 | 27 | 1.94±3.28 | 8.37±14.17 | 1.3±2.44 |
| **10 visits** | 19 | 63 | 4.82±3.54 | 42.2±32.12 | 6.13±4.61 |
| **15 visits** | 30 | 100 | 10.74±1.49 | 85.16±5.70 | 16.83±3.28 |
| **20 visits** | 30 | 100 | 18.43±1.48 | 170.46±31.90 | 22.8±4.32 |
| **Open pollination** | 30 | 100 | 18.6±1.03 | 185.7±29.10 | 17.90±3.70 |

**Plate 24: Pollen collectors (*A. cerana*- left and *A. florea*- right)**

**Plate 25: Nectar collectors (*A. cerana*- left and *A. florea*- right)**

per cent after one visit, and 64.5 per cent after 12 visits per flower. The pumpkin weight and number of seeds increased with number of visits (Jaycox *et al.*, 1975). Similarly, Kauffeld and Nelson (1982) also reported that the yield of pickling cucumber was highest in plots caged with *A. mellifera* than open plots and was lowest in control plots. Similar findings were reported by Battraglini (1969) who showed in *C. pepo* that pistillate flowers set maximum fruits when exposed to bees.

In the present study, a single visit was sufficient for fruit set with fruit weight of 2.1±6.41g and the number of seeds was 0.2±0.53. Maximum number of fruits set, per cent fruit set, fruit length, fruit weight and seed numbers were (30, 100, 18.43 ± 1.48, 170.46 ± 31.90 and 22.8 ± 4.32, respectively), recorded at 20 visits/flower/day followed by 30, 100, 10.74±1.49, 85.16±5.70 and 16.83±3.28 respectively, with 15 visits/flower/day (Table 35). The present findings are in agreement with the reports of Conner (1969) who examined that a single bee visit to a pistillate flower often resulted in well-shaped cucumber. The other findings reveled that at least 10 bee visits were necessary to ensure pollination under all conditions, whereas 8 to 12 visits per blossom were needed for yield uniformity in cucumber (Stephen, 1970). Similarly, Collison (1976) observed that 15 to 20 bee visits were needed to get uniform cucumbers and multiple bee visits increased the average number of seeds, which resulted in better and maximum fruit weight. In the present study, though there was a fruit set in a single visit made by the pollinator per flower but the fruit weight and seed numbers were very negligible. From the present findings and earlier reports it is confirmed that fruit yield can be increased by increase in number of bee visits per flower.

### 4.4.2 Time of visit and per cent fruit set

Data from time of pollinator visit and per cent fruit set experiment showed that >40 per cent fruit set was observed between 10.00 to 16.00h with a maximum fruit set of 96.67 and 83.33 per cent with visitation between 10.00-12.00h and 12.00-14.00h, respectively (Table 36).

Though pollinators are active throughout the day, it was found that visitation in the afternoon hours between 08.00 and 12.00h was more important for higher fruit set as maximum stigma receptivity recorded at this time of the day (Fig. 24). Among all the pollinators, *A. cerana* and *A. florea* are more adapted with bitter gourd ecosystem because the activity of these species temporally matched with pollen viability, stigma receptivity and nectar production.

### 4.4.3 Fruit set and seed number in *A. cerana*, *A. florea* and non-*Apis* pollination

The data on efficient pollinator in relation to fruit weight and seed numbers revealed that *A. cerana* was found to be significantly superior and a better pollinator in bitter gourd for gaining more fruit weight (128.71±31.67g) and seed numbers (15.18±3.19), followed by *A. florea* (82.79±13.93g of fruit weight and 9.29±1.72 seed number). The least efficiency was obtained by non-*Apis* pollinators with fruit weight of 25.99±5.49g and seed numbers of 4.77±1.66. The decreasing order of efficiency in relation fruit weight and seed numbers in bitter gourd were *A. cerana*>*A. florea*>Non-*Apis* pollinators (Table 37 and Fig. 25 & 26). Kauffeld and Nelson (1982) reported that

**Table 36: Time of visit and per cent fruit set (n = 30 flowers)**

| Parameters / Time | Total no of flowers tagged | No of fruits set | Percent fruit set |
|---|---|---|---|
| **6-8 AM** | 30 | 5 | **16.67** |
| **8-10 AM** | 30 | 10 | **33.33** |
| **10-12 PM** | 30 | 29 | **96.67** |
| **12-2 PM** | 30 | 25 | **83.33** |
| **2-4 PM** | 30 | 12 | **40.00** |
| **4-6 PM** | 30 | 3 | **10.00** |
| **6-7 PM** | 30 | 0 | **0.00** |

**Table 37: Comparison between visitation by *Apis* and Non-*Apis* species to bitter gourd flowers on fruit weight and seed number (n= 50 fruits)**

| Parameters / Species | Fruit wt. (g) | No of seeds |
|---|---|---|
| ***A. cerana* (A)** | 128.71±31.67 | 15.18±3.19 |
| ***A. florea* (B)** | 82.79±13.93 | 9.29±1.72 |
| **Non-*Apis* (C)** | 25.99±5.49 | 4.77±1.66 |
| | **Z Test** | |
| **A*B** | 9.38* | 11.48* |
| **A*C** | 22.59* | 20.48* |
| **C*D** | 26.82* | 13.37* |

***z-critical value 1.96, * -Significant at 0.05 level***

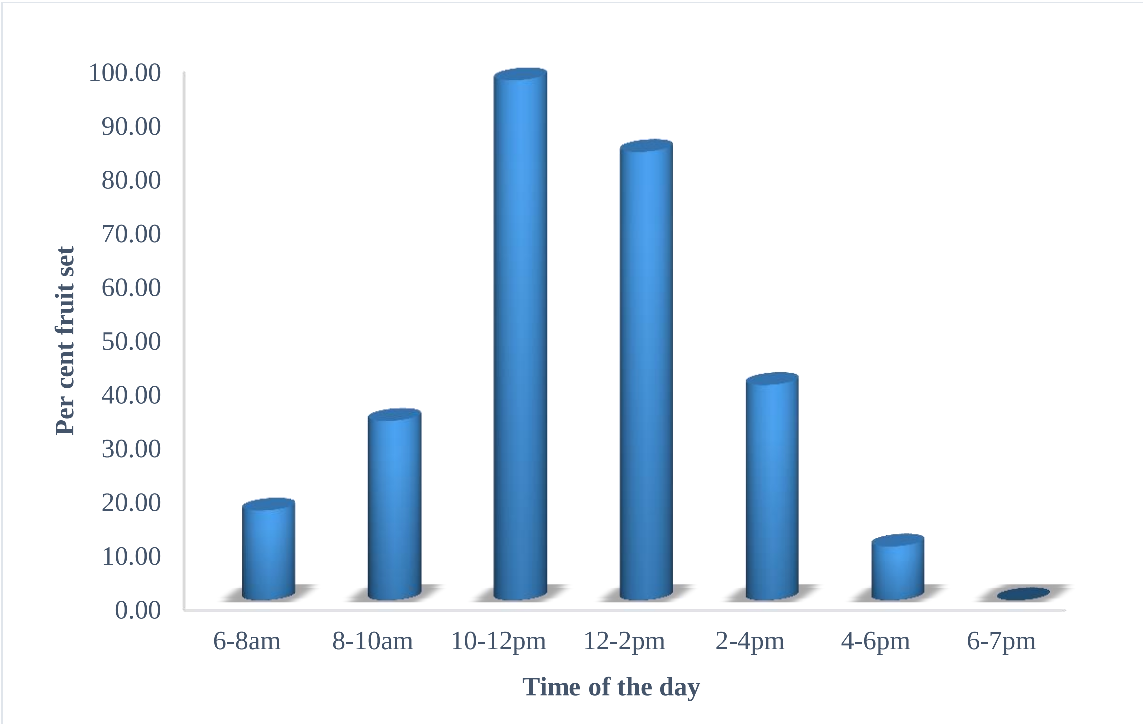


**Fig. 24: Relationship between time of pollinator visitation on fruit set**

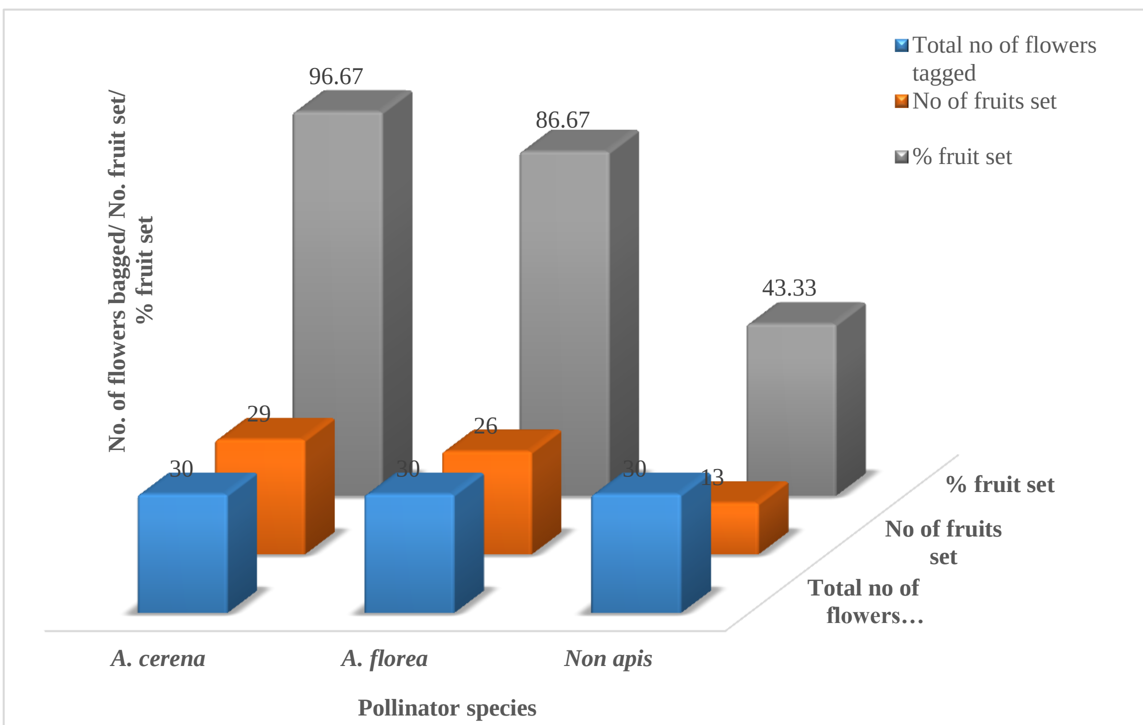


**Fig. 25: Per cent fruit set in bitter gourd by *A. cerana, A. florea* and non-*Apis* pollination**

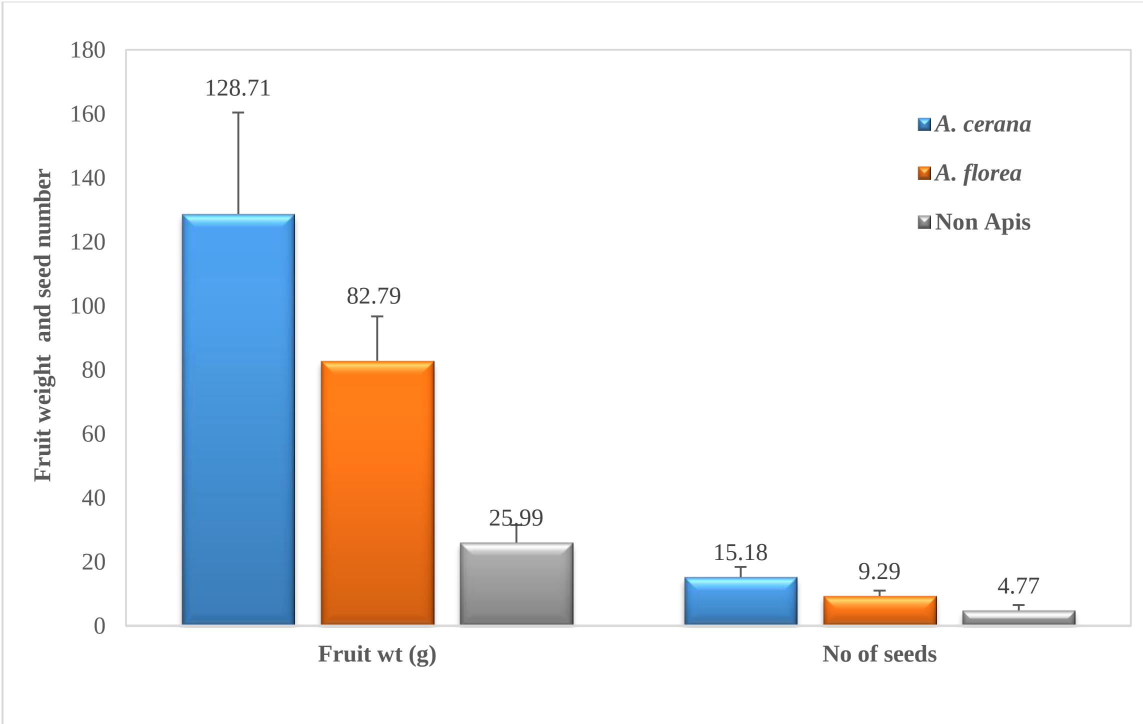


**Fig. 26: Fruit set and seed number in *A. cerana*, *A. florea* and Non-*Apis* in bitter gourd**

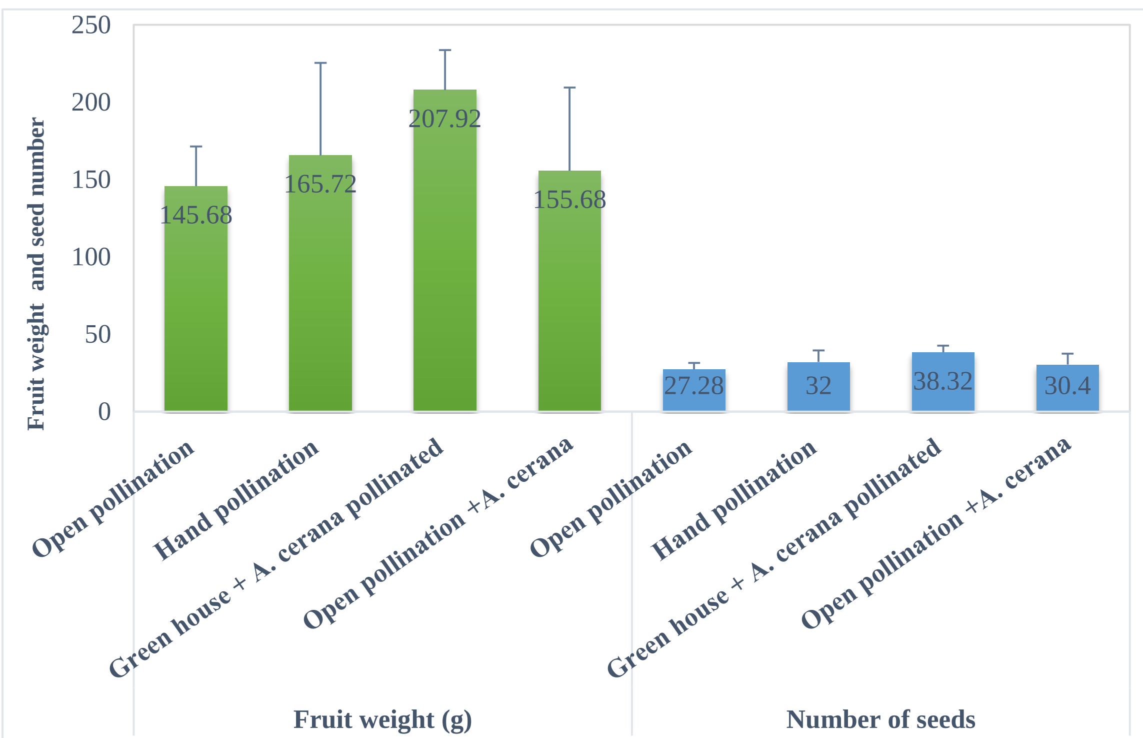


**Fig. 27: Fruit set and seed number with different pollination treatments in bitter gourd**

the yield of pickling cucumber was highest in the plots caged with *A. mellifera* than open plots and lowest in control plots, as in present study. Similarly, Carr and Davidar (2015) showed that levels of pollinator dependency ranged to 76 per cent in bitter gourd for better yield. In present study, *A. cerana* was considered as efficient pollinator because of rapid flight that helped it to visit maximum number of flowers. Their visitation frequency inturn increased the pollination efficiency.

### 4.4.4 Fruit set and seed number in Open v/s Hand v/s Greenhouse + *A. cerana* pollinated v/s Open pollination + *A. cerana* pollination

The data on comparison of the fruit weight and seed numbers obtained in the treatments *viz*., open pollination, hand pollination, green house with *A. cerana* colony and open pollination supplemented with *A. cerena* in bitter gourd revealed that, green house housed with *A. cerana* colony was significantly superior over remaining treatments and recorded maximum fruit weight of 207.92g and seed numbers of 38.32, followed by hand pollination (165.72 g (fruit weight) and 32.00 (seed numbers)) being on par with open pollination supplemented with *A. cerena* and only open pollination with fruit weight of 155.68 g and 145.68 g, respectively and seed numbers of 30.40 and 27.28, respectively (Plate 26, 27 and 28).

Similar results were also obtained by Thakur and Rana (2008), who studied the effect of honeybee, hand and open pollination on quality and quantity of cucumber at Solan, Himachal Pradesh. These results indicated that significantly higher fruit set was observed in hand pollination (75.68 %), followed by honeybee (74.96 %) and open pollination (62.09 %). Though the highest fruit set was obtained from hand pollinated crop, healthy fruit set was in honey bee pollinated crop (92.22 %) compared to hand (85.85 %) and open pollination (79.64 %). Similarly, weight of fruits (1184.5g), number of seeds per fruit (472.8), fruit size (28.8 cm) and weight of 1000-seeds (29.14 g) were maximum in honey bee pollination compared to other modes of pollination.

Similarly, Calin *et al.* (2008) in cucumber crop observed that the number of fruits/plant was significantly higher in the honey bee pollination treatment than in hand pollination treatment for the three genotypes. In pollination with honey bees treatment, a higher number of seeds were harvested than in the hand pollination treatment. Honey-bees were very efficient in pollination of cucumber flowers, resulting in increase of seed quantities per fruit in two hybrids ranging from 150 % (‘Cornirom’) to 214 % (‘Cornişa’), as compared to hand pollination.

The present studies are in agreement with Santos *et al.* (2008), who studied the pollination of cucumber, *C. sativus* by the stingless bees, in greenhouses in Brazil. They revealed that in the open field, fewer cucumbers were produced than in greenhouses that housed bee colonies. This finding is possibly due to the smaller amount of flowers produced in the open field plot. Most fruit quality parameters in the open field area, not protected against unfavorable climatic conditions, the plants produced fewer flowers than the plants in the greenhouses. The highest cucumber yield (with the highest amount of perfect fruits) was found in those greenhouses which housed the stingless bees as pollinators. These results demonstrated that stingless bees can be successfully and efficiently used as pollinators of greenhouse cucumbers during the *winter* season.

In the present study, green house along with *A. cerana* colony gave significantly greater yield when compared to others. The greater yield may be explained by two factors *i.e., A. cerana* pollination and congenial conditions that were suitable for both bitter gourd as well as *A. cerana* activity. However, the construction of green house for bitter gourd seed production incurs cost. Hence, it is feasible to go for production of bitter gourd under open conditions. In open conditions, since hand pollination requires expert personnel and is labour intensive for seed production, deployment of honey bees for open pollination in open conditions is best suited. This method is less costly has high economic value, yields maximum fruits with more viable seeds (Table 38 and Fig. 27).

#### 4.4.5 Fruit set and seed number in Open v/s Hand v/s control pollination during *Kharif*-2014, *Rabi*-2014 and *Summer*-2015

The results revealed that there was no significant difference in open and hand pollinated plots in relation to fruit weight and seed numbers across all the seasons. However, highest fruit weight (241.56±28.93 g, 200.26±51.53 g and 207.98±38.78 g) and seed numbers (32.98±6.70, 22.8±5.38 and 24.72±5.40) were obtained during *kharif*-2014, *rabi*-2014 and *summer*-2015, respectively in hand pollination when compared to open pollination with the fruit weight of 232.88±40.39 g, 191.32±27 g and 179.82±51.78 g, respectively and seed numbers of 24.38±8.04, 18.74±3.50 and 16.32±6.14, respectively. These results suggest that open pollination was as good as hand pollination with respect to fruit weight and seed number (Table 39 and Fig. 28).

Deyto and Cervancia (2009) observed that fruit set in insect-pollinated (78 %) and hand-pollinated (80 %) flowers did not significantly vary in bitter gourd. Likewise, there was no significant difference in fruit weight, length, diameter and number of seeds between both methods, as in the current study. Another study made by Kuberappa *et al.* (2006) who demonstrated that fruit weight (5066.25 g), fruit volume (4985.00 ml) and pulp ratio (10.28 %) were maximum in open pollination of pumpkin compared to other modes of pollination. There was significant difference in open and hand pollination as opined by Mann (1953) in muskmelon who studied the per cent fruit set from hand and open pollinations in four tests. It was shown further that, fruit set was much more uniform from day to day for open than for hand pollination. Open-pollinated flowers had produced larger fruits and more seeds than hand-pollinated flowers.

The discrepancies in yield of summer squash was explained by Manjula (2007) who revealed that fruit weight, fruit volume, number of sound seeds per fruit and seed weight were maximum in open pollinated crop, followed by *A. cerana, A. florea* and *T. iridipennis* pollinated crop. Similar results were also obtained by Nidagundi and Sattagi, (2005), who reported significantly higher fruit weight (129.21g) obtained in open pollinated as against 72.09 and 62.44 g in open pollinated and caged plot without bees, respectively and yield of 118.87 kg as against 68.63 and 45.23 kg in open pollinated and caged plots without bees, respectively.

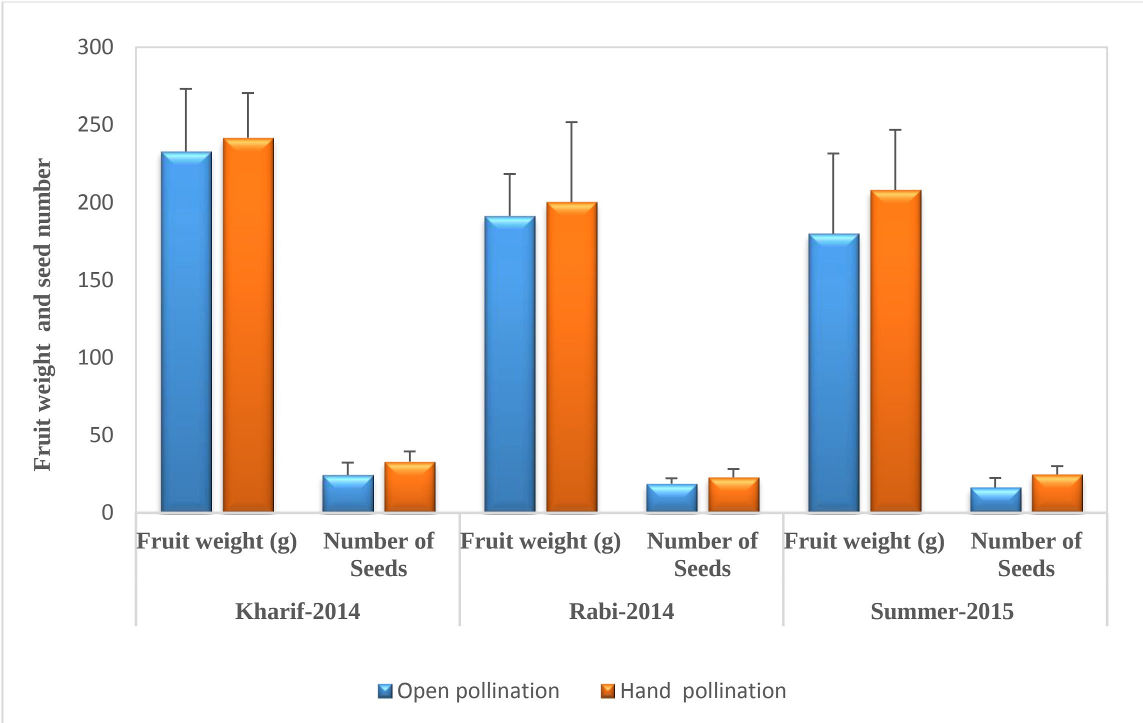


**Fig. 28: Fruit set and seed number in Open v/s Hand pollination during *Kharif*-2014, *Rabi*-2014 and *Summer*-2015**

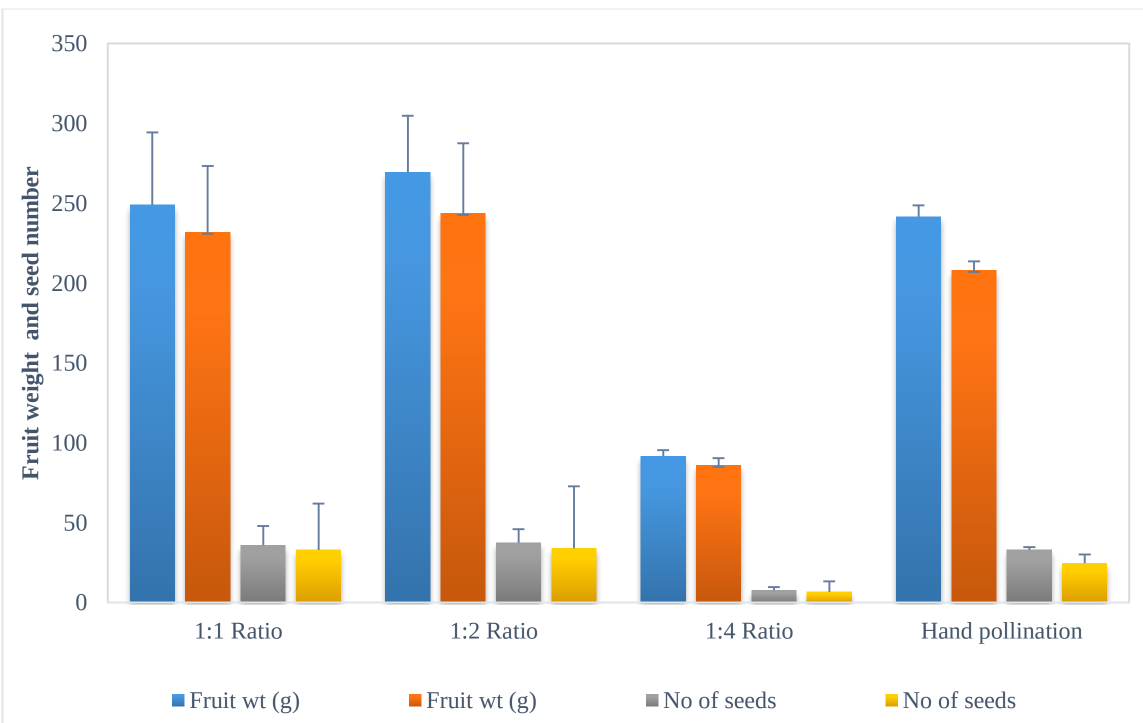


**Fig. 29: Fruit set and seed number in 1:1, 1:2 and 1:4 (Male: Female) ratio in bitter gourd during *Kharif*-2016 and *Summer*-2015 season**

**Plate 26: Fruit set in open pollination**

**Plate 27: Fruit set in hand pollination**

**Plate 28: Fruit set under green house condition**

**Plate 29: Aborted fruit without pollination**

**Table 38: Comparison of fruit weight and seed number with different pollination treatment (n=25 fruits)**

| Treatments | Fruit weight (g) | Number of seeds |
|---|---|---|
| **Open pollination (A)** | 145.68 | 27.28 |
| **Hand pollination (B)** | 165.72 | 32.00 |
| **Green house + *A. cerana* pollinated (C)** | 207.92 | 38.32 |
| **Open pollination + *A. cerana* (D)** | 155.68 | 30.40 |
| **T test** | | |
| **A*B** | -1.40 NS | -3.47 NS |
| **A*C** | 7.64* | 13.89* |
| **A*D** | -0.82 NS | -2.21 NS |
| **B*C** | 3.07* | 4.51* |
| **B*D** | 0.58 NS | 1.02 NS |
| **C*D** | 4.65 * | 5.29 * |

***T-Critical Value: 2.06; *Significant at 5% level; NS- Non significant***

**Table 39: Comparison of fruit set and seed number in open v/s hand pollination during *kharif*-2014, *rabi*-2014 and *summer*-2015 (n= 50 fruits)**

| Parameters / Treatments | *Kharif*-2014 | | *Rabi*-2014 | | *Summer*-2015 | |
|---|---|---|---|---|---|---|
| | **Fruit Weight (g)** | **Number of Seeds** | **Fruit Weight (g)** | **Number of Seeds** | **Fruit Weight (g)** | **Number of Seeds** |
| **Open pollination (A)** | 232.88±40.39 | 24.38±8.04 | 191.32±27 | 18.74±3.50 | 179.82±51.78 | 16.32±6.14 |
| **Hand pollination (B)** | 241.56±28.93 | 32.98±6.70 | 200.26±51.53 | 22.8±5.38 | 207.98±38.78 | 24.72±5.40 |
| **Control** | 0 | 0 | 0 | 0 | 0 | 0 |
| **Z test** | | | | | | |
| **A*B** | -1.24 (NS) | -5.81 (NS) | -1.09 (NS) | -4.47 (NS) | -3.13 (NS) | -7.26 (NS) |

***z- Critical Value: 1.96; NS- Non significant***

### 4.4.6 Fruit set and seed number in Open v/s Hand pollination across season *Kharif*-2014, *Rabi*-2014 and *Summer*-2015

The comparison was also made on the fruit weight and seed numbers obtained across the seasons *viz*., *kharif*-2014 versus *rabi*-2014, *kharif*-2014 versus *summer*-2015 and *rabi*-2014 versus *summer*-2015 in hand and open pollinated systems in bitter gourd (Table 40 and Fig. 28). The results revealed that fruit weight obtained was significantly different in *kharif*-2014 versus *rabi*-2014 in both hand pollinated crop (241.56±28.93 g and 200.26±51.53 g) compared to open pollinated crop (232.88±40.39 g and 191.32±27 g, respectively). There was also a significant difference in terms of fruit weight obtained in both hand and open pollination when comparison made on *kharif*-2014 versus *summer*-2015 in bitter gourd crop. The fruit weight in hand pollination was found to be more during *kharif*-2014 (241.56±28.93 g) when compared to *summer*-2015 (207.98±38.78 g). Similar results were also obtained in open pollination condition, where *kharif*-2014 (232.88±40.39 g) was significantly superior and better season over *summer*-2015 (179.82±51.78 g) for maximum fruit set and seed numbers. However, there was no significant difference when *rabi*-2014 was compared with *summer*-2015 in relation to the fruit weight, gained by bitter gourd crop in both hand (200.26±51.53 g and 207.98±38.78 g, respectively) and open pollination (191.32±27 g and 179.82±51.78 g, respectively).

The seed numbers obtained also showed significant difference between the systems (32.98±6.70 and 22.8±5.38 (Hand pollinated); 24.38±8.04 and 18.74±3.50 (Open pollinated) when comparison was made on *kharif*-2014 versus *rabi*-2014 seasons respectively. Similar trend was observed in case of *kharif*-2014 versus *summer*-2015, where both hand (32.98±6.70 and 24.72±5.40, respectively) and open pollination (24.38±8.04 and 16.32±6.14, respectively) showed significant difference. The results on comparison of *rabi*-2014 versus *summer*-2015 on seed numbers showed a non-significant difference in hand pollination (22.8±5.38 and 24.72±5.40, respectively), but open pollination system showed a significant difference (18.74±3.50 and 16.32±6.14, respectively) (Table 40 and Fig. 29).

## 4.5 Seed production in different male and female parent lines ratios

### 4.5.1 Fruit set and seed number in 1:1, 1:2 and 1:4 (Male: Female) ratios in *summer*-2015 and *kharif*-2016

During *kharif*-2016, significantly more fruit weight was recorded when male and female lines were maintained at the ratio of 1:1 (249.12 ± 45.30 g), 1:2 (269.38 ± 41.63 g) and 1:4 (91.52 ± 12.04 g) compared to *summer*-2015, where the fruit weights were 231.16 ± 35.38g, 243.43 ± 43.86 g and 85.94 ± 8.38 g, respectively. Similarly, the seed numbers were also more in *kharif*-2016 (35.88 ± 3.85, 37.50 ± 4.52 and 7.52 ± 2.06, respectively) when compared to *summer*-2015 (32.96 ± 7.10, 33.94 ± 5.530 and 6.62 ± 1.78, respectively) (Table 41, 42 and Fig. 29).

Similarly, the comparison of fruit weight and seed numbers were also made for different sex ratios of male and female flowers *i.e.*, 1:1, 1:2 and1:4 ratios in bitter gourd maintained during *kharif*-2016 and *Summer*-2015 seasons (Table 41, 42 and Fig. 29). The results revealed that the treatment male to female (1:2) ratio was found to be significantly

**Table 40: Comparison of fruit set and seed number in open v/s hand pollination across seasonal variation during *kharif*-2014, *rabi*-2014 and *summer*-2015 (n= 50 fruits)**

| Treatments / Seasons | Hand pollination | | Natural pollination | |
|---|---|---|---|---|
| | **Fruit weight (g)** | **Number of Seeds** | **Fruit weight (g)** | **Number of Seeds** |
| ***Kharif*-2014** | 241.56±28.93 | 32.98±6.70 | 232.88±40.39 | 24.38±8.04 |
| ***Rabi*-2014** | 200.26±51.53 | 22.8±5.38 | 191.32±27 | 18.74±3.50 |
| ***Summer*-2015** | 207.98±38.78 | 24.72±5.40 | 179.82±51.78 | 16.32±6.14 |
| **Z test** | | | | |
| **A*B** | 4.94* | 8.38* | 6.05* | 4.55* |
| **A*C** | 4.91* | 6.79* | 5.71* | 5.64* |
| **B*C** | -0.85 (NS) | -1.78 (NS) | 1.39 (NS) | 2.42* |

***z- Critical Value: 1.96; Significant at 0.05 level; NS- Non significant***

**Table 41: Comparison of fruit set and seed number in different planting ratios of male and female lines of bitter gourd during *kharif*-2016 and *summer*-2015 (n= 50 fruits)**

| Parameters / Seasons | 1:1 Ratio | | 1:2 Ratio | | 1:4 Ratio | |
|---|---|---|---|---|---|---|
| | Fruit weight (g) | No. of seeds | Fruit weight (g) | No. of seeds | Fruit weight (g) | No. of seeds |
| ***Kharif*-2016** | 249.12±45.30 | 35.88±3.85 | 269.38±41.63 | 37.50±4.52 | 91.52±12.04 | 7.52±2.06 |
| ***Summer*-2015** | 231.16±35.38 | 32.96±7.10 | 243.43±43.86 | 33.94±5.530 | 85.94±8.38 | 6.62±1.78 |
| **Z Test** | | | | | | |
| **A*B** | 2.20* | 2.55* | 3.00* | 3.52* | 2.69* | 2.33* |

***z - critical value 1.96, * -Significant at 0.05 level; NS- Non significant***

**Table 42: Comparison of fruit set and seed number in 1:1, 1:2 and 1:4 (Male: Female) ratio in bitter gourd across seasonal variation during *kharif*-2016 and *summer*-2015 season (n= 50 fruits)**

| Treatments | *Kharif*-2016 | | *Summer*-2015 | |
|---|---|---|---|---|
| | Fruit wt (g) | No. of seeds | Fruit wt (g) | No. of seeds |
| **1:1 Ratio (A)** | 249.12±45.30 | 35.88±3.85 | 231.78±35.38 | 32.96±7.10 |
| **1:2 Ratio (B)** | 269.38±41.63 | 37.50±4.52 | 243.72±43.86 | 33.94±5.53 |
| **1:4 Ratio (C)** | 91.52±12.03 | 7.52±2.06 | 85.94±8.37 | 6.62±1.78 |
| **Hand pollination(D)** | 241.56±28.93 | 32.98±6.69 | 207.98±38.77 | 24.72±5.40 |
| **Z Test** | | | | |
| **A*B** | -2.32 NS | -1.92 NS | -1.49 NS | -0.76 NS |
| **A*C** | 23.77** | 45.84** | 28.35** | 25.43** |
| **A*D** | 0.99 | 2.65* | 3.20* | 6.52* |
| **B*C** | 29.01** | 42.61** | 24.98** | 33.24** |
| **B*D** | 3.87* | 3.95* | 4.31* | 8.43* |
| **C*D** | 33.85** | 25.68** | 21.75** | 22.49** |

***z - critical value 1.96, * -Significant at 0.05 level, ** -Significant at 0.01 level and NS- Non significant***

superior over remaining treatments in obtaining the maximum fruit weight (269.38 g), followed by male to female ratio of 1:1 being on par with hand pollination treatment with fruit weight of 249.12 and 241.56 g, respectively during *kharif*-2016. The least fruit weight (91.52 g) was obtained in male to female to ratio of 1:4. The highest mean seed numbers (37.50 fruit$^{-1}$) was observed in 1:2 ratio, being on par with 1:1 ratio (35.88 seeds fruit$^{-1}$), followed by hand pollination with a mean seed numbers of 32.98 fruit$^{-1}$. The least seed number (7.52 fruit$^{-1}$) was observed in male to female ratio of 1:4 plot during *kharif*-2016.

In *summer*-2015, the maximum mean fruit weight (243.72 g) and mean seed numbers (33.94 fruit$^{-1}$) were observed in 1:2 ratio being on par with 1:1 ratio with a mean fruit weight of 231.78 g and mean seed numbers of 32.96 fruit$^{-1}$. This was followed by hand pollination with a mean fruit weight of 207.98 g and mean seed numbers of 24.72 fruit$^{-1}$. Least fruit weight (85.94 g fruit$^{-1}$) and seed numbers (6.62 fruit$^{-1}$) were observed in 1:4 ratio. The overall result suggests that maintenance of male and female ratio of 1:2 across different seasons for honey bee pollination results in maximum fruits with better seeds.

#### 4.5.2 Germination test and seed viability test of open pollination, hand pollination, *A. cerana* + green house, male and female lines at the ratios of 1:1, 1:2 and 1:4 in bitter gourd

The germination test was carried out for resultant seeds of bitter gourd. Among the treatments, significantly higher seed germination per cent (81.00 %) was noticed in green house with *A. cerana* followed by open pollination (75.00 %). Whereas, lowest was observed in hand pollination (71.00 %). Similarly, among the different planting ratios (male: female), the highest seed germination per cent was recorded in 1: 2 ratio (72.00 %), followed by 1:1 ratio (62.00 %) and lowest (46.00 %) was noticed in 1:4 ratio (Table 43 Fig. 30 and Plate 30). Rao and Suryanarayan (1989) reported that in addition to quantity, the insect pollination in general also brought about high germination in onion seeds.

The mean seedling length was measured for resultant seeds of bitter gourd. Among the different treatments the significantly higher mean shoot and root length (7.05 ± 0.68 and 13.18 ± 1.16) was noticed in *A. cerana* + green house, followed by open pollination (6.17 ± 1.44 and 12.48 ± 1.29). Whereas, lowest was observed in hand pollination (6.03 ± 1.25 and 12.03 ± 1.08). Similarly, among the different planting ratio (male: female) the highest was recorded in 1: 2 ratio (6.95 ± 1.03 and 11.33 ± 1.24), followed by (10.90 ± 1.28) in 1:1 and lowest (5.32 ± 0.65 and 9.29 ± 0.75) was noticed in 1:4 ratio (Table 43 and Fig. 30). The present results endorsed by the findings of Sattigi *et al.,* (2001) who reported that bee pollination influence the root length to an extent of 8.34 to 8.69cm in niger. Patil *et al.,* (2000) reported that root length was influenced by spraying of Bee-Q (12.5 and 15 g/l) in sesamum and Nidagundi (2004) on bitter gourd. The bee pollination influence the root length, shoot length and seedling vigour index in bitter gourd.

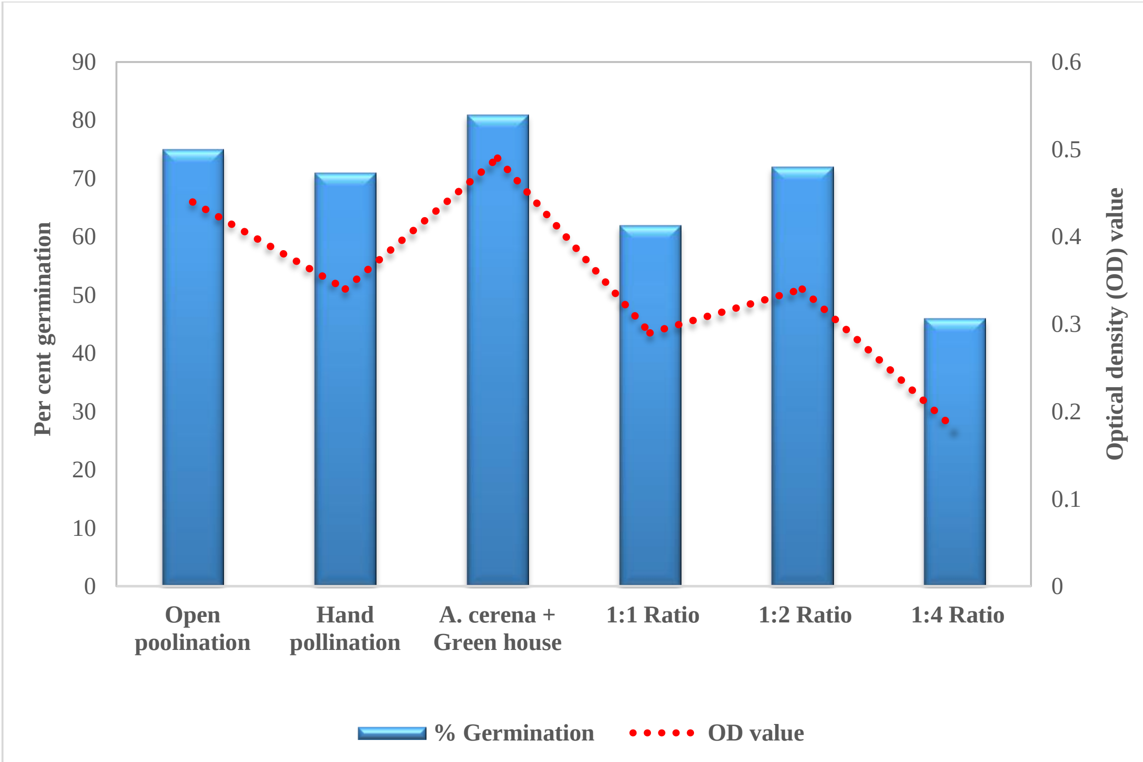


**Fig. 30: Per cent germination and optical density value in open pollination, hand pollination, *A. cerana* + green house, 1:1, 1:2 and 1:4 ratio in bitter gourd**

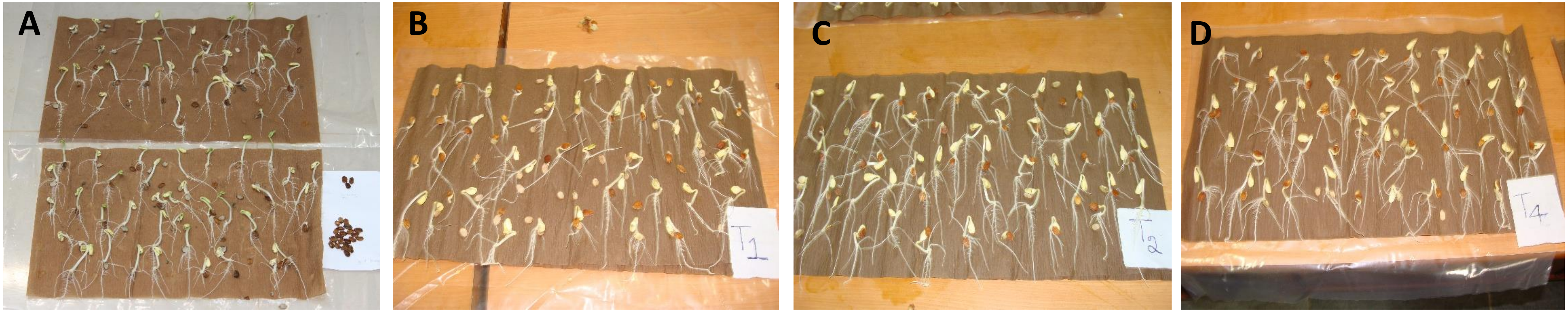


**Plate 30: Germination test; A: *A.cerana* + Green house; B: 1:1 Ratio; C: 1:2 Ratio; D: 1:4 Ratio**

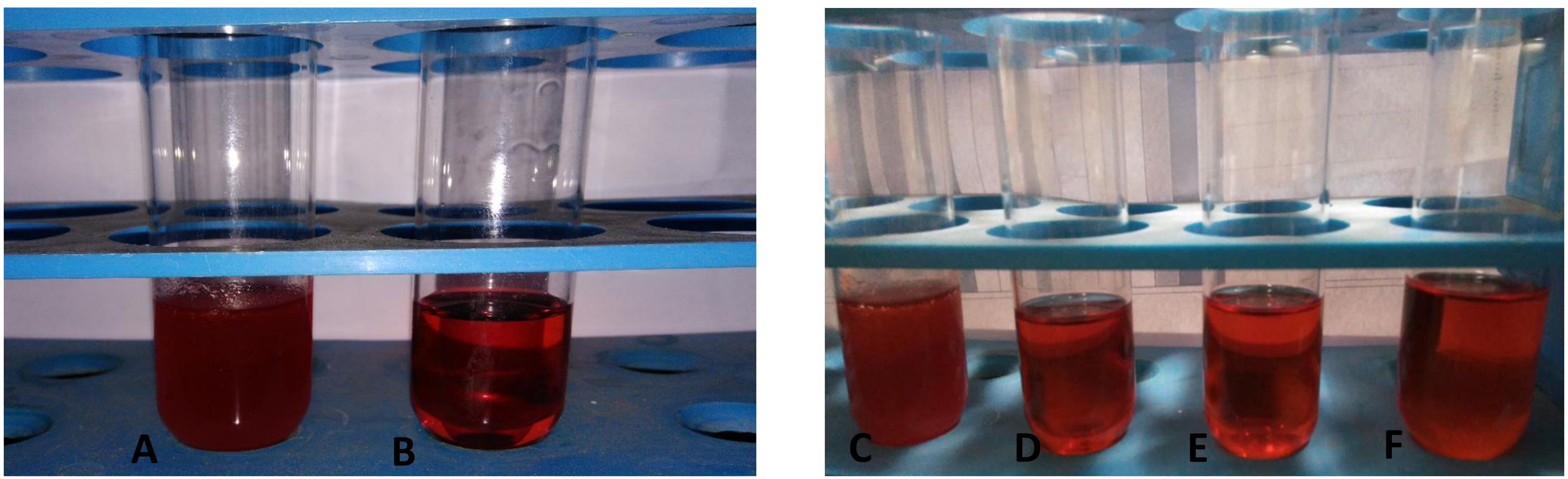


**Plate 31: Total dehydrogenase enzyme (TDH) activity test**

**A: Open pollination; B: Hand pollination; C: *A.cerana* + Green house; D: 1:1 Ratio; E: 1:2 Ratio; F: 1:3 Ratio**

**Table 43: Germination test and seed viability in open pollination, hand pollination and of seeds from different male to female ratios**

| **Treatments** | **Seed quality test** | | | |
|---|---|---|---|---|
| | **Germination %** | **Mean shoot length (cm)** | **Mean root length (cm)** | **TDH (A @ 480 nm) OD value** |
| **Natural pollination** | 75 | 7.41 | 13.77 | 0.439 |
| **Hand pollination** | 71 | 7.28 | 13.11 | 0.349 |
| ***A. cerana* + Green house** | 81 | 7.73 | 14.32 | 0.492 |
| **1:1 Ratio** | 62 | 6.14 | 11.37 | 0.297 |
| **1:2 Ratio** | 72 | 7.98 | 12.57 | 0.346 |
| **1:4 Ratio** | 46 | 5.97 | 10.09 | 0.186 |
| **S Em. ±** | **0.44** | **0.40** | **0.39** | **0.012** |
| **CD (P=0.01)** | **1.811** | **1.17** | **1.61** | **0.01** |
| **CV (%)** | **1.31** | **10.25** | **6.01** | **1.58** |

The total dehydrogenase enzyme activity test was carried out for resultant seeds of bitter gourd. Among the different treatments the significantly higher dehydrogenase enzyme activity (0.49) was noticed in *A. cerana* + green house, followed by open pollination (0.44). Whereas, lowest was observed in hand pollination (0.34). Similarly, among the different planting ratios (male: female) the highest dehydrogenase enzyme activity was recorded in 1: 2 ratio (0.34), followed by 1:1 ratio (0.29) and lowest (0.18) was noticed in 1:4 ratio (Table 43 Fig. 30 and Plate 31). Higher seed quality of seeds is obtained because of pollination by the honey bees when the flowers in the phase of fully functional generative organs. Therefore, honey bee pollination not only increases the fruit yield but also improves the quality of seeds.

**4.5.3 Cost of cultivation and valuation of pollination service in bitter gourd**

The effect of different pollination service on the fruit yield and seed yield of bitter gourd was determined and presented below. There was no fruit set in controlled experiment, whereas hand pollination and open pollination resulted in nearly 100 per cent fruit set. However, fruit weight and seed numbers were significantly higher in greenhouse + *A. cerana* pollinated flowers (207.92 g and 38.32 seeds, respectively) when compared to those that allowed for hand pollination (165.72g and 32.00 seeds, respectively) followed by open pollination + *A. cerana* (155.68g and 30.40). However, least fruit weight and seed numbers were recorded in open pollination (145.68 g and 27.28 seeds, respectively) (Table 45).

The total yield when flower visitors were prevented was 0 tonnes/acre. However, the fruit yield and seed yield were high in greenhouse + *A. cerana* pollinated crop (8.31 tonnes/acre and 6.43 quintals/acre) when compared to those that were allowed for hand pollination (6.62 tonnes/acre and 5.24 quintals/acre) followed by open pollination+ *A. cerana* pollination (6.22 tonnes/acre and 5.04 quintals/acre) and least in open pollination (5.82 tonnes/acre and 3.81 quintals/acre). Taking the current market price of bitter gourd seeds for rupees 1200/- per kg of seeds the value of pollination service amounts to rupees 4,03,780/- (open pollination), 5,60,800/- (hand pollination), 6,03,393/- (greenhouse + *A. cerana*) and 5,46,020/- (open pollination+ *A. cerana* pollination) in bitter gourd (Table 45) after deducting the cost of cultivation (Table 44).

The cost benefit ratio was estimated for four pollination services. The B: C ratio was found to be high in open pollination + *A. cerana* pollination (1:8.73) followed by hand pollination (1: 8.25) and open pollination (1: 7.40). Greenhouse+ *A. cerana* pollinated crop had least B: C ratio (1: 3.57). The pollinators are used for the most economical and environmental friendly approach towards the increase in both fruit yield and seed yield of cross pollinated crops (Free, 1970).

The estimated B:C ratio of open pollination + *A. cerana* pollination was found to be higher compared to other pollination services which suggested that deployment of *A. cerana* hives in open pollination is best suited in order to obtain high fruit yield and seed number with low cost of cultivation. Though the ovule number per female flower was nearly 60 in bitter gourd but only a maximum seed set 38 and 27 was achieved. The study indicated that there is deficit in pollinator population and hence there is a need for

**Table 44: Cost of cultivation of bitter gourd**

| Treatments / Particulars | Natural pollination (Rs.) | Hand pollination (Rs.) | Greenhouse + *A. cerena* (Rs.) | Natural pollination + *A. cerena* (Rs.) |
|---|---|---|---|---|
| **Land/field preparation** | 7,000.00 | 7,000.00 | 7,000.00 | 7,000.00 |
| **Transplanting** | 8,000.00 | 8,000.00 | 8,000.00 | 8,000.00 |
| **Weeding** | 11,000.00 | 11,000.00 | 11,000.00 | 11,000.00 |
| **Irrigation** | 6,000.00 | 6,000.00 | 6,000.00 | 6,000.00 |
| **Plant protection** | 8,000.00 | 8,000.00 | 8,000.00 | 8,000.00 |
| **Fertilizers** | 8,000.00 | 8,000.00 | 8,000.00 | 8,000.00 |
| **Staking** | 7,500.00 | 7,500.00 | 7,500.00 | 7,500.00 |
| **Skilled labours (15 days)** | - | 13,500.00 | - | - |
| **Green house construction** | - | - | 1,61,167.00 | - |
| **Bee Hive** | - | - | 8000.00 | 8,000.00 |
| **Total (Rs.)** | **54,500.00** | **68,000.00** | **1,69,167.00** | **62,500.00** |

***6 labours/acre employed for hand pollination and bagging @ Rs.150/- per day***

**Table 45. Valuation of pollination service to bitter gourd seed production**

| Treatments | Fruit weight (g) (n = 30) | Seed number (n = 30) | Seed weight (g) (n = 30) | Fruit yield (t/ac) | Seed yield (q/ac) | Gross income (Rs.) | Cost of cultivation (Rs.) | Net income (Rs.) | B: C Ratio |
|---|---|---|---|---|---|---|---|---|---|
| **Open pollination** | 145.68 | 27.28 | 0.35 | 5.83 | 3.81 | 4,58,280.00 | 54,500.00 | 4,03,780.00 | **1: 7.40** |
| **Hand pollination** | 165.72 | 32.00 | 0.41 | 6.63 | 5.24 | 6,28,800.00 | 68,000.00 | 5,60,800.00 | **1: 8.25** |
| **Green house + *A. cerana*** | 207.92 | 38.32 | 0.42 | 8.32 | 6.43 | 7,72,560.00 | 1,69,167.00 | 6,03,393.00 | **1: 3.57** |
| **Open pollination + *A. cerana*** | 155.68 | 30.40 | 0.41 | 6.23 | 5.04 | 6,05,520.00 | 62,500.00 | 5,46,020.00 | **1: 8.73** |

***Yield obtained based on mean fruit weight and mean fruit number @ 6667 plants/acre***
***Price of seeds @ Rs.1200/kg***

introduction of bee colonies for higher seed set for seed production. Honey bees are chief insect pollinators for this crop. Therefore, there is a need to conserve and manage the native pollinator populations so that farmers can get good quality and quantity of bitter gourd fruits with high viable seeds. From the above results it is very clear that bees can be effectively used for seed production.

# VI SUMMARY

Bitter gourd (*Momordica charantia* L.) is the most popular, annual tropical vegetable crop widely grown in India. It is monoecious in nature, bearing male and female flowers at different positions on the same plant. In bitter gourd, pistillate flowers are rewardless and these rewardless pistillate flowers mimic the staminate flowers and are pollinated by deceit. However, lack of pollination can be a major limiting factor, because inadequate pollination can result not only in reduction of yield but also in delayed yield with a high percentage of inferior fruits. Therefore, conservation and management of insect pollinators is gaining importance day by day for which studies on the floral biology in relation to pollinators, pollinator diversity and abundance, species richness, pollination success, fruit set and seed production in bitter gourd was studied. Hence, the present investigation on "Role of flower visitors in bitter gourd (*M. charantia* L.) pollination and seed production" was carried out for three seasons during 2014-2016 at the University of Agricultural Sciences, Bengaluru and in farmers fields near Rajanukunte, Bengaluru rural district located in the south eastern dry zone of Karnataka state. The results of the investigation are summarized below.

In all the three seasons (*kharif*-2014, *rabi*-2014 and *summer*-2015) bitter gourd plants (Variety- Arka Haritha) started flowering 40 to 45 days after sowing and blooming period varied from 55 to 60 days. Male flower buds took an average of 17 to 19 days, whereas female buds took 5 to 7 days for their complete development. The male flowers dropped off on the same day by7.00 pm while female flowers withered away on next morning. Anthesis commenced around 2.00 am and continued till 8.00 am with the opening of pistillate flowers followed by staminate flowers. Anther dehiscence commenced immediately after opening of the flower. Staminate flowers offered rewards (nectar & pollen) for flower visitors, while the pistillate flowers were rewardless. Pollen grains of bitter gourd were round in shape with three distinct germpores and measured 0.060 mm in diameter. The ovary had three carpels each with 16 to 20 ovules. The maximum pollen germination was observed in 10 per cent sucrose solution with 0.01 per cent boric acid. Longevity of flowers was for one day. Pollen viability, stigma receptivity and nectar production was found maximum from 10.00h to 14.00h and coincided with peak activity of pollinators (*Apis cerana* and *A. florea*). The overall ratio between staminate and pistillate flowers was 18:1 per plant. The overall ratio of pollen-ovules in a plant *i.e.,* ranged from 3161.87 to 3528.18 pollen grains to ovule.

A total of 27 species of flower visitors were recorded on bitter gourd belonging to 11 families of 3 orders. Of these, 16 were Hymenopterans (59.25 per cent); five belonged to Diptera (18.51 per cent) and six species to Lepidoptera (22.22 per cent). The order Hymenoptera was represented by 4 families including eight species of Apidae (50.00 per cent), six species of Halictidae (37.5 per cent), one species of Scolidae (6.25 per cent) and one species of Formicidae (6.25 per cent).

Among the flower visitors, *Apis* bees (*A. cerana* and *A. florea*) were more abundant (70.13 per cent) when compared to non-*Apis* species (29.86). *A. cerana* (50.35 per cent) was more abundant than *A. florea* (19.77 per cent) in all the three seasons. Bee foraging activity in bitter gourd started early morning around 6.00am, the combined activity of both *Apis* and non-*Apis* species remained more or less throughout the day.

The diversity of pollinators remained almost same throughout the day with diversity value ranging from 0.53-0.68 in all the three seasons. There was one peak activity in morning hours. The dominance and diversity for the flower visitors increased as the per cent floral abundance during subsequent weeks increased. Correlation studies between pollinator abundance and weather parameters depicted variable relationships. The study clearly showed significant positive relationship of pollinator activity/abundance with floral abundance rather than minor changes in weather parameters.

Foragers of both the species, *A. cerana* and *A. florea* spent relatively more time on staminate flowers (23 and 6 seconds, respectively) than on pistillate flowers (2 and 1 seconds, respectively). *A. cerana* appeared to be more efficient pollinator since it visited more number of flowers per trip (310 ± 31.07), spent less time per flower (109 ± 9.96 minutes) and covered greater distance per unit time (72.00 ± 6.57). As the sex ratio of the flowers was male-biased (ranged from 18:1 to 20:1), this would mean greater number of male flowers visited, hence greater diversity of pollen collected inturn increased the pollination efficiency. Numerous staminate flowers in bitter gourd ensures high pollen flow and enough pollen dusted on the foragers body such that single "chance" visit could have enough pollen deposititon on the stigma for fruit set.

Each staminate and pistillate flower in bitter gourd crop received an average of 29.40 and 10.90 visits/day, respectively. *A. cerana* and *A. florea* collected both nectar and pollen during morning hours, but during later part of the day a few pollen collectors shifted to nectar collection, probably because of lower pollen availability.

Foraging behaviour of the two species of honey bees in bitter gourd crop indicated that bees do not seem to discriminate between the sexes of flowers. *A. cerana* seems to visit greater number of flowers that are close to each other, while *A. florea* tended to visit fewer and farther flowers. It appeared that the combined effect of both species and non-*Apis* species would benefit bitter gourd pollination, because the former species may have greater density of pollen while the latter species might have greater diversity.

There was a significant increase in the fruit set (nearly 100 per cent), fruit size and weight, number of seeds per fruit in plants left for open and hand pollination over bagged plants (0 per cent), and this clearly indicated that bitter gourd is highly cross pollinated crop and completely depends on insect pollinators. Both hand and open pollination gave nearly 100 per cent fruit set. Open pollination was same as that of hand pollination with respect to fruit weight and seed numbers.

The data on comparison of the fruit weight and seed numbers obtained in the treatments *viz*., open pollination, hand pollination, green house with *A. cerana* colony and open pollination supplemented with *A. cerena* in bitter gourd revealed that, green house with *A. cerana* colony was significantly superior, showing maximum fruit weight (207.92g) and seed numbers (38.32), followed by hand pollination, which was on par with open pollination supplemented with *A. cerena* and open pollination.

Similarly, the fruit weight and seed numbers for different sex ratios of male and female lines in bitter gourd during *Kharif*-2016 and *Summer*-2015 seasons revealed that the treatment male to female ratio of 1:2 was significantly superior over remaining treatments in obtaining maximum fruit weight (269.38g) and seed number (37.50/per fruit) with high germination per cent and more viable seeds, followed by male to female ratio of 1:1 (fruit weight of 249.12g/fruit and seed numbers of 35.88 seeds/fruit). The least fruit weight (91.52g/fruit) and seed number (7.52/fruit) were observed in male to female ratio of 1:4 plot.

The total yield when flower visitors were prevented was found to be 0 tones/acre. However, the fruit yield and seed yield were high in greenhouse + *A. cerana* pollinated crop (8.31 tonnes/acre and 6.43 quintals/acre, respectively) compared to hand pollination (6.62 tonnes/acre and 5.24 quintals/acre) followed by open pollination supplemented with *A. cerana* colony (6.22 tonnes/acre and 5.04 quintals/acre). However, least fruit yield and seed yield was observed in only open pollination (5.82 tonnes/acre and 3.81 quintals/acre, respectively).

The estimated B:C ratio of open pollination + *A. cerana* pollination was found to be higher compared to other pollination services which suggested that deployment of *A. cerana* hives in open pollination is best suited in order to obtain high fruit yield and seed number with low cost of cultivation. Though the ovule number per female flower was nearly 60 in bitter gourd but only a maximum seed set 38 and 27 was achieved. The study indicated that there is deficit in pollinator population and hence there is a need for introduction of bee colonies for higher seed set for seed production. Honey bees are chief insect pollinators for this crop. Therefore, there is a need to conserve and manage the native pollinator populations so that farmers can get good quality and quantity of bitter gourd fruits with more viable seeds. From the above results it is very clear that bees can be effectively used for seed production.

The overall results reveal that there is a complex evolutionary co-adaptation between bitter gourd and their pollinators and therefore, much further investigations need to be done to understand the clear picture about rewardless pistillate flowers. There is positive indication that the flower visitors are very important in fruit set of bitter gourd, hence it is essential to conserve the native pollinators.

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**Appendix 1: General climatic condition of GKVK**

| Month | RF (mm) | Temp(ºC) | | RH (%) | |
|---|---|---|---|---|---|
| | | Max. | Min. | Max. | Min. |
| **Weather – 2014** | | | | | |
| January | 0 | 27.6 | 14.6 | 92 | 41 |
| February | 0 | 29.1 | 17.5 | 87 | 39 |
| March | 10 | 32.2 | 18.2 | 78 | 37 |
| April | 25.5 | 34.7 | 21.1 | 80 | 33 |
| May | 81.4 | 33.2 | 21.2 | 86 | 38 |
| June | 92 | 30.9 | 20.6 | 88 | 46 |
| July | 13.4 | 28.3 | 19.7 | 91 | 43 |
| August | 117.4 | 28.2 | 19.5 | 93 | 56 |
| September | 128.6 | 28.5 | 19.4 | 91 | 54 |
| October | 428.4 | 28.1 | 18.8 | 94 | 56 |
| November | 29.4 | 26.9 | 16.3 | 90 | 54 |
| December | 1 | 26.6 | 16.2 | 90 | 48 |
| Total | 927.1 | 354.3 | 223.1 | 1060 | 545 |
| Average | | 29.52 | 18.59 | 88.33 | 45.41 |
| **Weather – 2015** | | | | | |
| January | 10 | 27.4 | 15.2 | 91 | 45 |
| February | 0 | 29.9 | 15.3 | 86 | 42 |
| March | 0 | 32.2 | 18.9 | 85 | 37 |
| April | 142.1 | 32.1 | 21 | 84 | 41 |
| May | 140.2 | 31.4 | 20.6 | 87 | 45 |
| June | 100 | 29.3 | 20 | 90 | 51 |
| July | 66 | 2.3 | 19.5 | 91 | 53 |
| August | 71 | 29.3 | 19.6 | 92 | 50 |
| September | 254.6 | 28.7 | 19.2 | 91 | 54 |
| October | 80.8 | 29.3 | 19.1 | 89 | 52 |
| November | 180.4 | 25.3 | 17.9 | 94 | 65 |
| December | 4.2 | 27.6 | 19.9 | 91 | 52 |
| Total | 1049.3 | 324.8 | 226.2 | 1071 | 587 |
| Average | | 27.06 | 18.85 | 89.25 | 48.91 |
| **Weather – 2016** | | | | | |
| January | 2.4 | 27.5 | 14.7 | 90 | 47 |
| February | 0 | 31.2 | 16.2 | 85 | 38 |

**Appendix 2: Date of first flower opening of bitter gourd crop during *Kharif*-2014, *Rabi*-2014 and *Summer*-2015 (n=30 plants)**

| Plant No. | ***Kharif*-2014** | | | ***Rabi*-2014** | | | ***Summer*-2015** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Date of sowing** | **Date of first flower** | **No. of days required** | **Date of sowing** | **Date of first flower** | **No. of days required** | **Date of sowing** | **Date of first flower** | **No. of days required** |
| **1** | 13-Jul-14 | 20-Aug-14 | 39 | 4-Nov-14 | 15-Dec-14 | 42 | 20-Apr-15 | 31-May-15 | 41 |
| **2** | 13-Jul-14 | 23-Aug-14 | 42 | 4-Nov-14 | 11-Dec-14 | 38 | 20-Apr-15 | 3-Jun-15 | 45 |
| **3** | 13-Jul-14 | 20-Aug-14 | 39 | 4-Nov-14 | 19-Dec-14 | 46 | 20-Apr-15 | 30-May-15 | 40 |
| **4** | 13-Jul-14 | 17-Aug-14 | 36 | 4-Nov-14 | 17-Dec-14 | 44 | 20-Apr-15 | 31-May-15 | 41 |
| **5** | 13-Jul-14 | 21-Aug-14 | 40 | 4-Nov-14 | 18-Dec-14 | 45 | 20-Apr-15 | 3-Jun-15 | 45 |
| **6** | 13-Jul-14 | 24-Aug-14 | 43 | 4-Nov-14 | 15-Dec-14 | 42 | 20-Apr-15 | 2-Jun-15 | 44 |
| **7** | 13-Jul-14 | 21-Aug-14 | 40 | 4-Nov-14 | 20-Dec-14 | 47 | 20-Apr-15 | 31-May-15 | 41 |
| **8** | 13-Jul-14 | 20-Aug-14 | 39 | 4-Nov-14 | 18-Dec-14 | 45 | 20-Apr-15 | 1-Jun-15 | 43 |
| **9** | 13-Jul-14 | 21-Aug-14 | 40 | 4-Nov-14 | 17-Dec-14 | 44 | 20-Apr-15 | 2-Jun-15 | 44 |
| **10** | 13-Jul-14 | 24-Aug-14 | 43 | 4-Nov-14 | 14-Dec-14 | 41 | 20-Apr-15 | 30-May-15 | 40 |
| **11** | 13-Jul-14 | 21-Aug-14 | 40 | 4-Nov-14 | 18-Dec-14 | 45 | 20-Apr-15 | 1-Jun-15 | 43 |
| **12** | 13-Jul-14 | 20-Aug-14 | 39 | 4-Nov-14 | 16-Dec-14 | 43 | 20-Apr-15 | 30-May-15 | 40 |
| **13** | 13-Jul-14 | 24-Aug-14 | 43 | 4-Nov-14 | 14-Dec-14 | 41 | 20-Apr-15 | 2-Jun-15 | 44 |
| **14** | 13-Jul-14 | 20-Aug-14 | 39 | 4-Nov-14 | 18-Dec-14 | 45 | 20-Apr-15 | 3-Jun-15 | 45 |
| **15** | 13-Jul-14 | 24-Aug-14 | 43 | 4-Nov-14 | 15-Dec-14 | 42 | 20-Apr-15 | 1-Jun-15 | 43 |
| **16** | 13-Jul-14 | 23-Aug-14 | 42 | 4-Nov-14 | 18-Dec-14 | 45 | 20-Apr-15 | 31-May-15 | 41 |
| **17** | 13-Jul-14 | 19-Aug-14 | 38 | 4-Nov-14 | 12-Dec-14 | 39 | 20-Apr-15 | 31-May-15 | 41 |
| **18** | 13-Jul-14 | 19-Aug-14 | 38 | 4-Nov-14 | 17-Dec-14 | 44 | 20-Apr-15 | 2-Jun-15 | 44 |
| **19** | 13-Jul-14 | 18-Aug-14 | 37 | 4-Nov-14 | 17-Dec-14 | 44 | 20-Apr-15 | 3-Jun-15 | 45 |
| **20** | 13-Jul-14 | 20-Aug-14 | 39 | 4-Nov-14 | 19-Dec-14 | 46 | 20-Apr-15 | 31-May-15 | 41 |
| **21** | 13-Jul-14 | 22-Aug-14 | 41 | 4-Nov-14 | 15-Dec-14 | 42 | 20-Apr-15 | 4-Jun-15 | 46 |
| **22** | 13-Jul-14 | 18-Aug-14 | 37 | 4-Nov-14 | 19-Dec-14 | 46 | 20-Apr-15 | 2-Jun-15 | 44 |
| **23** | 13-Jul-14 | 23-Aug-14 | 42 | 4-Nov-14 | 17-Dec-14 | 44 | 20-Apr-15 | 3-Jun-15 | 45 |
| **24** | 13-Jul-14 | 24-Aug-14 | 43 | 4-Nov-14 | 14-Dec-14 | 41 | 20-Apr-15 | 30-May-15 | 40 |
| **25** | 13-Jul-14 | 21-Aug-14 | 40 | 4-Nov-14 | 16-Dec-14 | 43 | 20-Apr-15 | 31-May-15 | 41 |
| **26** | 13-Jul-14 | 22-Aug-14 | 41 | 4-Nov-14 | 16-Dec-14 | 43 | 20-Apr-15 | 31-May-15 | 41 |
| **27** | 13-Jul-14 | 21-Aug-14 | 40 | 4-Nov-14 | 17-Dec-14 | 44 | 20-Apr-15 | 2-Jun-15 | 44 |
| **28** | 13-Jul-14 | 20-Aug-14 | 39 | 4-Nov-14 | 18-Dec-14 | 45 | 20-Apr-15 | 1-Jun-15 | 43 |
| **29** | 13-Jul-14 | 21-Aug-14 | 40 | 4-Nov-14 | 14-Dec-14 | 41 | 20-Apr-15 | 30-May-15 | 40 |
| **30** | 13-Jul-14 | 20-Aug-14 | 39 | 4-Nov-14 | 17-Dec-14 | 44 | 20-Apr-15 | 1-Jul-15 | 43 |
| | | **Mean ± SD** | **40.03±1.94** | | **Mean ± SD** | **43.37±2.13** | | **Mean ± SD** | **42.60±1.92** |

**Appendix 3: Bud developmental time and longevity period of bitter gourd during *Kharif*-2014 (n=30 flowers)**

| Flower No. | Staminate flower | | | | | Pistillate flower | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Date of bud initiation** | **Date of Final bud formation** | **Date of anthesis** | **No. of days required for bud development** | **Longevity period** | **Date of bud initiation** | **Date of Final bud formation** | **Date of anthesis** | **No. of days required for bud development** | **Longevity period** |
| **1** | 21/9/14 | 08/10/14 | 09/10/14 | 18 | 1 | 1/10/14 | 07/10/14 | 08/10/14 | 7 | 1 |
| **2** | 21/9/14 | 10/10/14 | 11/10/14 | 20 | 1 | 1/10/14 | 08/10/14 | 09/10/14 | 8 | 1 |
| **3** | 21/9/14 | 08/10/14 | 09/10/14 | 18 | 1 | 1/10/14 | 07/10/14 | 08/10/14 | 7 | 1 |
| **4** | 21/9/14 | 09/10/14 | 10/10/14 | 19 | 1 | 1/10/14 | 07/10/14 | 08/10/14 | 7 | 1 |
| **5** | 21/9/14 | 08/10/14 | 09/10/14 | 18 | 1 | 1/10/14 | 06/10/14 | 07/10/14 | 6 | 1 |
| **6** | 21/9/14 | 10/10/14 | 11/10/14 | 20 | 1 | 1/10/14 | 07/10/14 | 08/10/14 | 7 | 1 |
| **7** | 21/9/14 | 09/10/14 | 10/10/14 | 19 | 1 | 1/10/14 | 05/10/14 | 08/10/14 | 5 | 1 |
| **8** | 21/9/14 | 07/10/14 | 08/10/14 | 17 | 1 | 1/10/14 | 05/10/14 | 07/10/14 | 5 | 1 |
| **9** | 21/9/14 | 10/10/14 | 11/10/14 | 20 | 1 | 1/10/14 | 07/10/14 | 08/10/14 | 7 | 1 |
| **10** | 21/9/14 | 08/10/14 | 09/10/14 | 18 | 1 | 1/10/14 | 07/10/14 | 08/10/14 | 7 | 1 |
| **11** | 21/9/14 | 08/10/14 | 09/10/14 | 18 | 1 | 1/10/14 | 04/10/14 | 05/10/14 | 4 | 1 |
| **12** | 21/9/14 | 10/10/14 | 11/10/14 | 20 | 1 | 1/10/14 | 06/10/14 | 07/10/14 | 6 | 1 |
| **13** | 21/9/14 | 08/10/14 | 09/10/14 | 18 | 1 | 1/10/14 | 08/10/14 | 09/10/14 | 8 | 1 |
| **14** | 21/9/14 | 09/10/14 | 10/10/14 | 19 | 1 | 1/10/14 | 06/10/14 | 07/10/14 | 6 | 1 |
| **15** | 21/9/14 | 08/10/14 | 09/10/14 | 18 | 1 | 1/10/14 | 08/10/14 | 09/10/14 | 8 | 1 |
| **16** | 21/9/14 | 10/10/14 | 11/10/14 | 20 | 1 | 1/10/14 | 06/10/14 | 07/10/14 | 6 | 1 |
| **17** | 21/9/14 | 10/10/14 | 11/10/14 | 20 | 1 | 1/10/14 | 08/10/14 | 09/10/14 | 8 | 1 |
| **18** | 21/9/14 | 09/10/14 | 10/10/14 | 19 | 1 | 1/10/14 | 07/10/14 | 08/10/14 | 7 | 1 |
| **19** | 21/9/14 | 09/10/14 | 10/10/14 | 19 | 1 | 1/10/14 | 08/10/14 | 09/10/14 | 8 | 1 |
| **20** | 21/9/14 | 09/10/14 | 10/10/14 | 19 | 1 | 1/10/14 | 08/10/14 | 09/10/14 | 8 | 1 |
| **21** | 21/9/14 | 08/10/14 | 09/10/14 | 18 | 1 | 1/10/14 | 04/10/14 | 05/10/14 | 4 | 1 |
| **22** | 21/9/14 | 10/10/14 | 11/10/14 | 20 | 1 | 1/10/14 | 08/10/14 | 09/10/14 | 8 | 1 |
| **23** | 21/9/14 | 08/10/14 | 09/10/14 | 18 | 1 | 1/10/14 | 06/10/14 | 07/10/14 | 6 | 1 |
| **24** | 21/9/14 | 10/10/14 | 11/10/14 | 20 | 1 | 1/10/14 | 05/10/14 | 07/10/14 | 5 | 1 |
| **25** | 21/9/14 | 08/10/14 | 09/10/14 | 18 | 1 | 1/10/14 | 06/10/14 | 07/10/14 | 6 | 1 |
| **26** | 21/9/14 | 09/10/14 | 10/10/14 | 19 | 1 | 1/10/14 | 06/10/14 | 07/10/14 | 6 | 1 |
| **27** | 21/9/14 | 10/10/14 | 11/10/14 | 20 | 1 | 1/10/14 | 06/10/14 | 07/10/14 | 6 | 1 |
| **28** | 21/9/14 | 07/10/14 | 08/10/14 | 17 | 1 | 1/10/14 | 06/10/14 | 07/10/14 | 6 | 1 |
| **29** | 21/9/14 | 10/10/14 | 11/10/14 | 20 | 1 | 1/10/14 | 04/10/14 | 05/10/14 | 4 | 1 |
| **30** | 21/9/14 | 09/10/14 | 10/10/14 | 19 | 1 | 1/10/14 | 08/10/14 | 09/10/14 | 8 | 1 |
| | | | **Mean ±SD** | **18.87 ±0.97** | | | | **Mean ±SD** | **6.46±1.28** | |

**Appendix 4: Bud developmental time and longevity period of bitter gourd during *Rabi*-2014 season (n=30 flowers)**

| Flower No. | Staminate flower | | | | | Pistillate flower | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Date of bud initiation | Date of final bud formation | Date of Anthesis | No. of days required for bud development | Longevity period | Date of bud initiation | Date of final bud formation | Date of Anthesis | No. of days required for bud development | Longevity period |
| **1** | 05/1/15 | 25/1/15 | 26/1/15 | 20 | 1 | 07/1/15 | 14/1/15 | 15/1/15 | 7 | 1 |
| **2** | 05/1/15 | 22/1/15 | 23/1/15 | 17 | 1 | 07/1/15 | 12/1/15 | 13/1/15 | 5 | 1 |
| **3** | 05/1/15 | 24/1/15 | 25/1/15 | 19 | 1 | 07/1/15 | 14/1/15 | 15/1/15 | 7 | 1 |
| **4** | 05/1/15 | 23/1/15 | 24/1/15 | 18 | 1 | 07/1/15 | 12/1/15 | 13/1/15 | 5 | 1 |
| **5** | 05/1/15 | 25/1/15 | 26/1/15 | 20 | 1 | 07/1/15 | 12/1/15 | 13/1/15 | 5 | 1 |
| **6** | 05/1/15 | 23/1/15 | 24/1/15 | 18 | 1 | 07/1/15 | 12/1/15 | 13/1/15 | 5 | 1 |
| **7** | 05/1/15 | 21/1/15 | 22/1/15 | 16 | 1 | 07/1/15 | 10/1/15 | 11/1/15 | 3 | 1 |
| **8** | 05/1/15 | 23/1/15 | 24/1/15 | 18 | 1 | 07/1/15 | 12/1/15 | 13/1/15 | 5 | 1 |
| **9** | 05/1/15 | 23/1/15 | 24/1/15 | 18 | 1 | 07/1/15 | 11/1/15 | 12/1/15 | 4 | 1 |
| **10** | 05/1/15 | 23/1/15 | 24/1/15 | 18 | 1 | 07/1/15 | 14/1/15 | 15/1/15 | 7 | 1 |
| **11** | 05/1/15 | 21/1/15 | 22/1/15 | 16 | 1 | 07/1/15 | 11/1/15 | 12/1/15 | 4 | 1 |
| **12** | 05/1/15 | 24/1/15 | 25/1/15 | 19 | 1 | 07/1/15 | 10/1/15 | 11/1/15 | 3 | 1 |
| **13** | 05/1/15 | 23/1/15 | 24/1/15 | 18 | 1 | 07/1/15 | 12/1/15 | 13/1/15 | 5 | 1 |
| **14** | 05/1/15 | 25/1/15 | 26/1/15 | 20 | 1 | 07/1/15 | 12/1/15 | 13/1/15 | 5 | 1 |
| **15** | 05/1/15 | 24/1/15 | 25/1/15 | 19 | 1 | 07/1/15 | 11/1/15 | 12/1/15 | 4 | 1 |
| **16** | 05/1/15 | 23/1/15 | 24/1/15 | 18 | 1 | 07/1/15 | 12/1/15 | 13/1/15 | 5 | 1 |
| **17** | 05/1/15 | 23/1/15 | 24/1/15 | 18 | 1 | 07/1/15 | 14/1/15 | 15/1/15 | 7 | 1 |
| **18** | 05/1/15 | 24/1/15 | 25/1/15 | 19 | 1 | 07/1/15 | 14/1/15 | 15/1/15 | 7 | 1 |
| **19** | 05/1/15 | 21/1/15 | 22/1/15 | 16 | 1 | 07/1/15 | 12/1/15 | 13/1/15 | 5 | 1 |
| **20** | 05/1/15 | 24/1/15 | 25/1/15 | 19 | 1 | 07/1/15 | 11/1/15 | 12/1/15 | 4 | 1 |
| **21** | 05/1/15 | 24/1/15 | 25/1/15 | 19 | 1 | 07/1/15 | 11/1/15 | 12/1/15 | 4 | 1 |
| **22** | 05/1/15 | 24/1/15 | 25/1/15 | 19 | 1 | 07/1/15 | 11/1/15 | 12/1/15 | 4 | 1 |
| **23** | 05/1/15 | 21/1/15 | 22/1/15 | 16 | 1 | 07/1/15 | 10/1/15 | 11/1/15 | 3 | 1 |
| **24** | 05/1/15 | 24/1/15 | 25/1/15 | 19 | 1 | 07/1/15 | 12/1/15 | 13/1/15 | 5 | 1 |
| **25** | 05/1/15 | 24/1/15 | 25/1/15 | 19 | 1 | 07/1/15 | 14/1/15 | 15/1/15 | 7 | 1 |
| **26** | 05/1/15 | 23/1/15 | 24/1/15 | 18 | 1 | 07/1/15 | 12/1/15 | 13/1/15 | 5 | 1 |
| **27** | 05/1/15 | 24/1/15 | 25/1/15 | 19 | 1 | 07/1/15 | 12/1/15 | 13/1/15 | 5 | 1 |
| **28** | 05/1/15 | 23/1/15 | 24/1/15 | 18 | 1 | 07/1/15 | 12/1/15 | 13/1/15 | 5 | 1 |
| **29** | 05/1/15 | 22/1/15 | 23/1/15 | 17 | 1 | 07/1/15 | 14/1/15 | 15/1/15 | 7 | 1 |
| **30** | 05/1/15 | 24/1/15 | 25/1/15 | 19 | 1 | 07/1/15 | 12/1/15 | 13/1/15 | 5 | 1 |
| | | | **Mean ±SD** | **18.23±1.17** | | | | **Mean ±SD** | **5.07±1.26** | |

**Appendix 5: Bud developmental time and Longevity period of bitter gourd in *Summer*-2015 season (n=30 flowers)**

| Flower No. | Staminate flower | | | | | Pistillate flower | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Date of bud initiation** | **Date of Final bud formation** | **Date of Anthesis** | **No. of days required for bud development** | **Longevity period** | **Date of bud initiation** | **Date of Final bud formation** | **Date of Anthesis** | **No. of days required for bud development** | **Longevity period** |
| **1** | 06/6/15 | 27/6/15 | 28/6/15 | 22 | 1 | 06/6/15 | 10/6/15 | 11/6/15 | 4 | 1 |
| **2** | 06/6/15 | 25/6/15 | 26/6/15 | 20 | 1 | 06/6/15 | 12/6/15 | 13/6/15 | 6 | 1 |
| **3** | 06/6/15 | 24/6/15 | 25/6/15 | 19 | 1 | 06/6/15 | 11/6/15 | 12/6/15 | 5 | 1 |
| **4** | 06/6/15 | 28/6/15 | 29/6/15 | 23 | 1 | 06/6/15 | 10/6/15 | 11/6/15 | 4 | 1 |
| **5** | 06/6/15 | 23/6/15 | 24/6/15 | 18 | 1 | 06/6/15 | 10/6/15 | 11/6/15 | 4 | 1 |
| **6** | 06/6/15 | 25/6/15 | 26/6/15 | 20 | 1 | 06/6/15 | 10/6/15 | 11/6/15 | 4 | 1 |
| **7** | 06/6/15 | 24/6/15 | 25/6/15 | 19 | 1 | 06/6/15 | 10/6/15 | 11/6/15 | 4 | 1 |
| **8** | 06/6/15 | 23/6/15 | 24/6/15 | 18 | 1 | 06/6/15 | 12/6/15 | 13/6/15 | 6 | 1 |
| **9** | 06/6/15 | 27/6/15 | 28/6/15 | 22 | 1 | 06/6/15 | 13/6/15 | 14/6/15 | 7 | 1 |
| **10** | 06/6/15 | 22/6/15 | 23/6/15 | 17 | 1 | 06/6/15 | 11/6/15 | 12/6/15 | 5 | 1 |
| **11** | 06/6/15 | 24/6/15 | 25/6/15 | 19 | 1 | 06/6/15 | 10/6/15 | 11/6/15 | 4 | 1 |
| **12** | 06/6/15 | 27/6/15 | 28/6/15 | 22 | 1 | 06/6/15 | 12/6/15 | 13/6/15 | 6 | 1 |
| **13** | 06/6/15 | 25/6/15 | 26/6/15 | 20 | 1 | 06/6/15 | 13/6/15 | 14/6/15 | 7 | 1 |
| **14** | 06/6/15 | 22/6/15 | 23/6/15 | 17 | 1 | 06/6/15 | 12/6/15 | 13/6/15 | 6 | 1 |
| **15** | 06/6/15 | 24/6/15 | 25/6/15 | 19 | 1 | 06/6/15 | 11/6/15 | 12/6/15 | 5 | 1 |
| **16** | 06/6/15 | 27/6/15 | 28/6/15 | 22 | 1 | 06/6/15 | 12/6/15 | 13/6/15 | 6 | 1 |
| **17** | 06/6/15 | 28/6/15 | 29/6/15 | 23 | 1 | 06/6/15 | 12/6/15 | 13/6/15 | 6 | 1 |
| **18** | 06/6/15 | 25/6/15 | 26/6/15 | 20 | 1 | 06/6/15 | 10/6/15 | 11/6/15 | 4 | 1 |
| **19** | 06/6/15 | 25/6/15 | 26/6/15 | 20 | 1 | 06/6/15 | 12/6/15 | 13/6/15 | 6 | 1 |
| **20** | 06/6/15 | 27/6/15 | 28/6/15 | 22 | 1 | 06/6/15 | 11/6/15 | 12/6/15 | 5 | 1 |
| **21** | 06/6/15 | 23/6/15 | 24/6/15 | 18 | 1 | 06/6/15 | 11/6/15 | 12/6/15 | 5 | 1 |
| **22** | 06/6/15 | 25/6/15 | 26/6/15 | 20 | 1 | 06/6/15 | 13/6/15 | 14/6/15 | 7 | 1 |
| **23** | 06/6/15 | 22/6/15 | 23/6/15 | 17 | 1 | 06/6/15 | 12/6/15 | 13/6/15 | 6 | 1 |
| **24** | 06/6/15 | 25/6/15 | 26/6/15 | 20 | 1 | 06/6/15 | 10/6/15 | 11/6/15 | 4 | 1 |
| **25** | 06/6/15 | 27/6/15 | 28/6/15 | 22 | 1 | 06/6/15 | 10/6/15 | 11/6/15 | 4 | 1 |
| **26** | 06/6/15 | 23/6/15 | 24/6/15 | 18 | 1 | 06/6/15 | 11/6/15 | 12/6/15 | 5 | 1 |
| **27** | 06/6/15 | 22/6/15 | 23/6/15 | 17 | 1 | 06/6/15 | 11/6/15 | 12/6/15 | 5 | 1 |
| **28** | 06/6/15 | 24/6/15 | 25/6/15 | 19 | 1 | 06/6/15 | 13/6/15 | 14/6/15 | 7 | 1 |
| **29** | 06/6/15 | 27/6/15 | 28/6/15 | 22 | 1 | 06/6/15 | 10/6/15 | 11/6/15 | 4 | 1 |
| **30** | 06/6/15 | 27/6/15 | 28/6/15 | 22 | 1 | 06/6/15 | 12/6/15 | 13/6/15 | 6 | 1 |
| | | | **Mean ±SD** | **19.90±1.92** | | | | **Mean ±SD** | **5.23±1.07** | |

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# Valuation of Pollination Service in Bitter Gourd (*Momordica charantia* L.) Seed Production

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## ABSTRACT

The present investigation on the pollination biology was carried out at the University of Agricultural Sciences, Bengaluru, India during 2014 - 2015. Flowering of bitter gourd started 40 to 45 days after germination. Anthesis commenced around 2.00 am and continued till 8.00 am with the opening of staminate flowers followed by pistillate flowers. Anther dehiscence commenced immediately after opening of the flower. The ovary had three carpels, each with 16 to 20 ovules. Pollen viability and stigma receptivity coincided with peak activity of pollinators (*Apis cerana* and *A. florea*). Longevity of flowers was one day. The total yield when flower visitors were prevented was 0 tonnes / acre.However, the fruit yield and seed yield was high ingreenhouse + *A. cerana* pollinated crop (8.31 tonnes / acre and 6.43 quintals / acre) but B: C ratio was found to be low (1:3.57) compared to other treatments. The B: C ratio was found to be high in natural pollination + *A. cerana* pollination (1:8.69) followed by hand pollination (1:8.25) and natural pollination (1:7.40).

Pollination is most important service in the ecosystem for the maintenance biodiversity of plants on earth. Insects play a vital role for increasing quality and quantity of any crop production. Inadequate pollination not only results in reduced yield but also in high percentage of inferior fruits (Mc Gregor, 1976).About 75 per cent of the total crops depend on pollination through insects for their reproduction. 87 of the total food crops depend entirely on pollinators and therefore, 35 per cent of the global food production is from the crops which depend on pollinators (Klien *et al.,* 2007). Through insect pollination and good management of pollinators, yield of the crops can be increased up to 50 to 60 per cent, 45 to 50 per cent and 100 to 150 per cent in fruits, oil seed and cucurbitaceous crops, respectively. The pollinators are used for the most economical and environmental friendly approach towards the increase in the yield of cross pollinated crops. The insects of family Apidae are the most reliable agents for pollination. Among members of Apidae, honey bees are particularly important pollinators as they are capable of carrying pollen and in the process, the plants visited by them are benefited (Tewari and Singh, 1983).

Entomophily in the crop production is more significant in crops like bitter gourd belonging to cucurbits, which are monoecious (male and female flowers are borne at different positions on the same plant). It is also grown as an ornamental and used extensively in medicine (Deyto and Cervancia, 2009). The open position of the bitter gourd flowers makes them easy for the pollinators to access and exploit floral rewards. The high male to female ratio achieves the production of sufficient amount of pollen deposits, thus resulting in effective pollination (Goulson, 1999). Keeping in view the importance of Entomophily in the bitter gourd crop (variety: ArkaHarita) production the current study was carried out to evaluate economics of pollination services.

The present investigation was carried out at the University of Agricultural Sciences, Bengaluru, India during 2014 - 2015. A fixed number of flowers (n=100) were tagged and observations were made on the floral biology such as anthesis (time of opening of flowers), anther dehiscence (release of pollen grains), floral longevity, ratio between staminate and pistillate flowers, pollen viability and stigma receptivity. In order to workout cost economics involved in pollination service,four setsofrandomly selected 25 flowers were covered individually using paper packets. One set was opened for hand pollination and the other set was allowed only for *A. cerana* pollination (1 colony) in the green house. Flowers of third set were tagged and left for open pollination. Flowers of fourth set were tagged and left for open pollination along with introducing an *A. cerana* colony. Observations were made on fruit weight, seed number, seed weight.

*Floral biology:* Bitter gourd plants started flowering 40 to 45 days after sowing and blooming period varied from 55 to 60 days. The male flower buds took an average of 17 to 19 days, whereas female buds took 5 to 7 days for their complete development. The male flowers dropped off on the same day at 6.00 pm to 7.00 pm while female flowers withered away next morning. The anthesis commenced around 2.00 am and continued till 8.00 am with the opening of staminate flowers followed by pistillate flowers. When the temperature is low, with high humidity, or the day is cloudy, opening is delayed and the flower closes permanently in the afternoon of the same day (McGregor and Todd, 1952). Anther dehiscence commenced immediately after opening of the flower. Pollen grains of bitter gourd were round in shape with three distinct germpores measures 0.060 mm in diameter. The ovary had three carpels each with 16 to 20 ovules. The maximum pollen germination was observed in 10 per cent sucrose solution with 0.01 per cent boric acid. Longevity of flowers was one day. Pollen viability and stigma receptivity was found maximum from 10.00h to 14.00h, coincided with peak activity of pollinators (*A. cerana* and *A. florea*).The male to female flower ratio was 18:1.

*Economics and yield:* The effect of different pollination treatments on the fruit yield and seed yield of bitter gourd was determined. There was no fruit set in controlled experiment, whereashand pollination and open pollination resulted nearly 100 per cent fruit set. However, fruit weight and seed numbers were significantly higher in greenhouse + one colony of *A. cerana* pollinated flowers (207.92g and 38.32seeds, respectively) when compared to those that allowed forhand pollination (165.72g and 32.00 seeds, respectively) followed byopenpollination + one colony of*A. cerana* (155.68g and 30.40). However, least fruit weight and seed numbers were recorded in open pollination alone (145.68g and 27.28 seeds, respectively) (Table II).

The total yield when flower visitors were prevented was 0 tonnes / acre. However, the fruit yield and seed yield were high in greenhouse + one colony of *A. cerana* pollinated crop (8.31 tonnes / acre and 6.43 quintals / acre) when compared to those that were allowed for hand pollination (6.62 tonnes / acre and 5.24 quintals / acre) followed by open pollination+ one colony of *A. cerana* pollination (6.22 tonne s/ acre and 5.04 quintals / acre) and least open pollination (5.82 tonnes/acre and 3.81 quintals/acre). Taking the current market price of bitter gourd of rupees 1200/- per kg of seeds the value of pollination service amounts to rupees 4,03,780/- (openpollination), 5,60,800/- (hand pollination), 6,03,393/- (greenhouse + one colony *A. cerana*) and 5,46,020/- (openpollination+ one colony *A. cerana*) in bitter gourd (Table II) after deducting the cost of cultivation (Table I).

The B:C ratio was found to be high in openpollination + one colony of *A. cerana* pollination (1:8.69) followed by hand pollination (1: 8.25) and open pollination (1: 7.40). greenhouse+ one colony of *A. cerana* pollinated crophad least B:C ratio (1: 3.57) (Table I). The pollinators are used for the most economical and environmental friendly approach towards the increase in both fruit yield and seed yield of cross pollinated crops (Free, 1970). The estimated B:C ratio of openpollination + one colony of *A. cerana* pollination was found to be higher compared to other pollination treatmentswhich suggest that use of *A. cerana* @ 2 hives / acre in open pollination is best in order to obtain high fruit yield and seed number (Table I) with low cost of cultivation.The present study implies that there is pollinators deficit in nature. Hence, there is a need to conserve and manage the native pollinator populations so that farmers can get good quality and quantity of bitter gourd fruits with high viable seeds.

TABLE I

*Cost of cultivation of bitter gourd*

| Treatments / Particulars | Open pollination (Rs.) | Hand pollination (Rs.) | Greenhouse + 1 Colony *A. cerena* (Rs.) | Open pollination + 1 Colony *A. cerena*(Rs.) |
|---|---|---|---|---|
| Land/field preparation | 7,000.00 | 7,000.00 | 7,000.00 | 7,000.00 |
| Transplanting | 8,000.00 | 8,000.00 | 8,000.00 | 8,000.00 |
| Weeding | 11,000.00 | 11,000.00 | 11,000.00 | 11,000.00 |
| Irrigation | 6,000.00 | 6,000.00 | 6,000.00 | 6,000.00 |
| Plant protection | 8,000.00 | 8,000.00 | 8,000.00 | 8,000.00 |
| Fertilizers | 8,000.00 | 8,000.00 | 8,000.00 | 8,000.00 |
| Staking | 7,500.00 | 7,500.00 | 7,500.00 | 7,500.00 |
| Skilled labours(15 days) | - | 13,500.00 | - | - |
| Green house construction | - | - | 1,61,167.00 | - |
| Bee Hive | - | - | 8000.00 | 8,000.00 |
| Total (Rs.) | 54,500.00 | 68,000.00 | 1,69,167.00 | 62,500.00 |

6 labours / acre employed for hand pollination and bagging @Rs. 150/- per day

Bee hive cost @ Rs. 4000/- per colony

TABLE II

*Valuation of pollination service to bitter gourd*

| Treatments\ | Fruit weight(g) (n=25) | Seed number (n=25) | Seed weight (g) (n=25) | Fruit yield t/ac | Seed yield q/ac | Gross income (Rs.) | Cost of cultivation (Rs.) | Net income (Rs.) | B:C Ratio |
|---|---|---|---|---|---|---|---|---|---|
| Open pollination | 145.68 | 27.28 | 0.35 | 5.827 | 3.81 | 4,58,280.00 | 54,500.00 | 4,03,780.00 | 1:7.40 |
| Hand pollination | 165.72 | 32.00 | 0.41 | 6.629 | 5.24 | 6,28,800.00 | 68,000.00 | 5,60,800.00 | 1:8.25 |
| Greenhouse+ 1 Colony *A. cerana* | 207.92 | 38.32 | 0.42 | 8.317 | 6.43 | 7,72,560.00 | 1,69,167.00 | 6,03,393.00 | 1:3.57 |
| Natural pollination+ 1 Colony *A. cerana* | 155.68 | 30.40 | 0.41 | 6.227 | 5.04 | 6,05,520.00 | 62,500.00 | 5,46,020.00 | 1:8.69 |

Yield obtained based on mean fruit weight and mean fruit number @ 6667 plants/acre
Price of seeds @ Rs.1200/kg of seeds

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# FLOWER VISITORS IN BITTER GOURD ECOSYSTEM : ABUNDANCE AND DIVERSITY

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**ABSTRACT : The present investigation on abundance and diversity of flower visitors in bitter gourd ecosystem was carried out at the Zonal Agricultural Research Station, Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences, Bangalore during kharif-2014. The data on visual counts of flower visitors with respect to their abundance in bitter gourd during kharif-2014 revealed that *Apis bees*, *Apis cerana* and *A.florea* were significantly larger in number and constituted nearly 65% when compared to other non-Apis species visiting bitter gourd flowers. A total of 27 species of flower visitors were recorded on bitter gourd belonging to 11 families of 3 orders. Among the flower visitors, *A.cerana* and *A.florea* were more abundant (70.13%) than other non-Apis species (29.86%). Malaise and intercept traps caught very low number of flower visitors. The maximum pollinator diversity remained same between 08.00 to 14.00 h except between 06.00 to 07.00 h and later the activity decreased gradually.**

**Key words :** *Bitter gourd, Flower visitors, Diversity and abundance.*

## INTRODUCTION

Bitter gourd (*Momordica charantia* L.) is one of the most popular, annual temperate/tropical vegetable crops probably originated in South East Asia. It is widely grown in India, Indonesia, Malaysia, China and tropical Africa. It is a monoecious climbing type herbaceous crop belonging to the family Cucurbitaceae, which consists of 130 genera and 900 species. Depending on the location, bitter gourd is known by different names - balsam pear, bitter melon, bitter cucumber and African cucumber (Heiser,1979).

The open nature of the bitter gourd flowers makes them easy for the pollinators to access and exploit floral rewards from male flowers. The high male to female ratio achieves the production of sufficient amount of pollen deposits, thus resulting in effective pollination. A successfully pollinated flower starts to develop fruit from second to fifth day after it had opened with petals detached, while un-pollinated flowers dry up and the ovary turns yellow on fifth day (Deyto and Cervancia,2009). Many investigations have consistently confirmed that yield levels can be increased to an extent of 50%-60% in fruits and plantation crops, 45%-50% in sunflower, sesamum and niger and 100%-150% in cucurbitaceous crops through good management of pollinators (Melnichenko and Khalifman,1960). Insect pollination of crops is an essential crop management practice and should be utilized skillfully by harnessing the activity of domestic honey bees, wild bees and other pollinators including solitary bees. Achievement of desired pollination lies in the planned and efficient use of honey bees to increase the yield as well as improving qualitative and quantitative parameters of the crop yield. Flowering phenology of bitter gourd ensures the cross-pollination for better fruit set and yield. The flowers of bitter gourd are usually monoecious, they produce male and female flowers separately on the same plant at different internodes.

Lack of pollination can be a major limiting factor, because inadequate pollination can result not only in reduction of yield but also in delayed yield with a high percentage of inferior fruits (Mc Gregor,1976). Literature on decline of pollinators worldwide has prompted a growing interest in the importance of pollinator diversity in both natural and crop ecosystems (Kevan,1999). Therefore, the conservation and management of insect pollinators is gaining importance day by day for which studies on the floral biology in relation to pollinators, pollinator diversity and abundance, are essential in bitter gourd. Hence, in this investigated the pollinator diversity and abundance in bitter gourd.

## MATERIAL AND METHODS

The present investigation on was carried out at the Zonal Agricultural Research Station, Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences, Bangalore. Arka Haritha variety was selected for the study. The experimental plot measuring 40 m x 20 m was selected for planting. The transplanting was done with a spacing of 100 cm between the rows and 60 cm between plants. The crop was cultivated by following all recommended package of practices of UAS, GKVK, Bangalore except plant protection measures.

**Flower visitors of bitter gourd :** Visual counting, sweep net collection, bee bowl counts, yellow pan trap count, malaise and intercept trap count methods were employed to catch/trap the insects visiting flowers of bitter gourd. The collected/trapped insects were then identified for proper record.

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**Visual scanning/counting :** Ad-libitum visual counting of flower visitors was done from 06.00 to 18.00 h on a given sampling day with a recording time of 15 minutes with a time gap of five minutes between two observations. The visual counting was repeated eight times in a season for every five days from the date of first flowering where every two sampling days represented 25, 50, 75 and >90 percent flowering of the crop. All insects visiting bitter gourd flowers per recording time were counted. Observations were recorded on the species of insects visiting the flowers and number of visits made by each species per recording time at different times of the day. Sampling day was divided into 12 time intervals of one hour each from 06.00 h to 18.00 h. This was done to record variation in species composition and their abundance, if any, in different times of the day.

**Sweep net collection of flower visitors :** Flower visitors of bitter gourd were also collected at regular intervals and in different times of the day using an insect sweep net. Sweep net samples were collected on different days with different flower densities. Insects collected from sweep net were brought to the laboratory, mounted using insect pins, properly dried and preserved for future identification. Identification of bee species was done using the available keys and the expertise available in the Biosystematics Lab, Department of Entomology, UAS, Bangalore.

**Bee bowl collection of flower visitors :** Bee bowl collection of flower visitors was done to monitor flowers visitors. Totally five colours of bee bowls (Yellow, White, Blue, Grey and Green) containing water with liquid soap were placed for the whole day on sampling date at five meter intervals in field, and this was repeated three times during the cropping period. The flower visitors collected in bee bowls were brought to the laboratory, cleaned, dried and preserved for further use (FAO,2008).

**Yellow pan trap :** Most insects get attracted to yellow colour, hence, yellow pan traps were used to catch many flying insects. The traps were half filled with water and a few drops of liquid soap added. The traps were randomly placed in the crop field with a distance of at least ten meters. The flower visitors collected in yellow pan trap were brought to the laboratory, washed, dried and preserved for further identification. The data collected from the above methods were used for analyzing the pollinator diversity and density.

**Statistical analysis :** The frequency of visits by each species was recorded to identify the most abundant species visiting bitter gourd flowers. Pollinator count data was used to compute Shannon-Wiener index of diversity (H) by using the following formula :

$H = \Sigma \, pi \times lnpi$

Where, pi is the proportion of the $i^{th}$ species of pollinator.

**Table. 1 Pollinator species visiting bitter gourd flowers.**

| Order | Family | Species |
|---|---|---|
| Hymenoptera | Apidae | *Apis cerana* Fabricius |
| | | *A.florea* Fabricius |
| | | *A.dorsata* Fabricius |
| | | *Tetragonula iridipennis* Smith |
| | | *Ceratina hieroglyphica* Smith |
| | | *C.binghami* Cockrell |
| | | *Braunsapis* sp. |
| | | *Xylocopa aestuans* Linnaeus |
| | Halictidae | *Lasioglossum* sp.1 |
| | | *Lasioglossum* sp.2 |
| | | *Lasioglossum* sp.3 |
| | | *Seladonia* sp. |
| | | *Nomoides* sp. |
| | | *Pachynomia* sp. |
| | Scolidae | *Scolid* wasp |
| | Formicidae | *Camponotus sericeus* Fabricius |
| Diptera | Syrphidae | *Ischiodon scuttellaris* Fabricius |
| | | *Eristalinus tabanoides* |
| Jaennicke | | |
| | | *E.aeneus* Scopoli |
| | Sarcophagidae | *Sarcophaga* sp. |
| | Calliphoridae | *Chrysomya* sp. |
| Lepidoptera | Lycaenidae | Blue butterfly |
| | Pieridae | *Eurema hecabe* Linnaeus |
| | | *Colotis etrida* Boisduval |
| | | *Anaphaeis aurota* Fabricius |
| | Nymphalidae | *Danus chrysippus* Linnaeus |
| | Hesperidae | *Pelopidas mathias* Fabricius |

## RESULTS AND DISCUSSION

**Flower visitors of bitter gourd :** A total of 27 species of flower visitors were recorded on bitter gourd belonging to 11 families of 3 orders. Of these, 16 were Hymenopterans (59.25%), five belonged to Diptera (18.51%) and six species to Lepidoptera (22.22%). The order Hymenoptera was represented by 4 families including eight species of Apidae (50.00%), six species of Halictidae (37.5%), one species of Scolidae (6.25%) and one species of Formicidae (6.25%). Among the flower visitors, *Apis* bees (*Apis cerana* and *A.florea*) were more abundant (70.13%) when compared to other non-*Apis* species (29.86). Within these two *Apis* species, *A.cerana* (50.35%) was more abundant than *A.florea* (19.77%) (Table.1).

Honey bees were observed to be the largest group (77.2%) of pollinating agents in cucurbits. Other insects such as ants (Tontz,1944), thrips (Annand,1926), beetles and solitary bees (Rosa,1925; Alex,1957 and Joycox *et al.*,1975) have been identified as possible pollinators of cucurbits. The density of insects on flowers depends on several factors such as flower shape, size, colour, availability of floral rewards and weather conditions (Mevetty *et al.*,1989). Insect pollinators have its specific ecological threshold level, below which activity does not occur. The ecological threshold required for a normal activity and its maintenance differ inter and intra-specificity depending upon the level of adaptability of a species in a given environment (Kapil and Jain,1980). The daily flight activity varies with the time of the day and meteorological variables, especially wind, rainfall, temperature and humidity (Sarviva,1985).

Grewal and Sidhu (1978,1979) reported *A.florea* as the predominant pollinator of bitter gourd followed by *A.dorsata*. They also reported Halictidae as pollinators in bitter gourd. Nidagundi and Sattagi (2005) reported that among the 10 species of pollinators in bitter gourd, *A.florea* was the most predominant, constituting 43.00% of the total pollinators, followed by *A.cerana* (26.00%), A.dorsata (13.00%) and other pollinators (18.00%). But, in the present study *A.cerana* was found to be the most frequent visitor of bitter gourd flowers.

Similar observations on the pollinator species of bitter gourd (*M.charantia* L.) were made by Deyto and Cervancia (2009) and stated that insects visiting the flowers of bitter gourd plant belonged to four different orders: Hymenoptera (*A.cerana*, *A.mellifera*, *Trigona* spp., *Halictus* spp., *Xylocopa* spp. and Formicidae), Lepidoptera (butterflies), Coleoptera (Chrysomelidae) and Diptera (*Calliphora* spp., Sarcophagidae and Syrphidae). Among these, honey bees (*A.mellifera* and *A.cerana*), stingless bees (*Trigona* spp.) and *Halictus* spp. were the major insect pollinators. According to Subhakar *et al.*

**Table. 2 Abundance of flower visitors (during 100% flowering) in bitter gourd in different times of the day during *Kharif*-2014.**

| Pollinator sp. | Time | | | | | | | | | | | | | Total | Mean ±SD | % Bees |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6-7 hrs. | 7-8 hrs. | 8-9 hrs. | 9-10 hrs. | 10-11 hrs. | 11-12 hrs. | 12-13 hrs. | 13-14 hrs. | 14-15 hrs. | 15-16 hrs. | 16-17 hrs. | 17-18 hrs. | 18-19 hrs. | | | |
| *A.cerana* | 24 | 98 | 116 | 85 | 77 | 65 | 28 | 22 | 16 | 8 | 1 | 0 | 0 | 540 | 41.54± 41.00 | 50.42 |
| *A.florea* | 0 | 3 | 6 | 12 | 16 | 30 | 42 | 31 | 21 | 2 | 1 | 1 | 0 | 165 | 12.69± 14.21 | 15.41 |
| *A.dorsata* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.08± 0.28 | 0.09 |
| *Tetragonula* sp. | 0 | 0 | 2 | 9 | 14 | 18 | 22 | 16 | 8 | 8 | 1 | 2 | 0 | 100 | 7.69± 7.69 | 9.34 |
| *Lasioglossum* sp. | 0 | 0 | 6 | 14 | 18 | 29 | 24 | 12 | 8 | 4 | 0 | 1 | 0 | 116 | 8.92± 9.84 | 10.83 |
| *C.hieroglyphica* | 0 | 0 | 0 | 1 | 0 | 3 | 6 | 12 | 2 | 1 | 0 | 0 | 0 | 25 | 1.92± 3.50 | 2.33 |
| *Braunsapis* sp. | 0 | 0 | 1 | 2 | 6 | 8 | 12 | 9 | 8 | 5 | 0 | 0 | 0 | 51 | 3.92± 4.27 | 4.76 |
| *Nomia* sp. | 0 | 0 | 0 | 1 | 2 | 7 | 8 | 7 | 2 | 1 | 0 | 0 | 0 | 28 | 2.15± 3.05 | 2.61 |
| Scolids | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.08± 0.28 | 0.09 |
| Lycanids | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 0 | 0 | 0 | 10 | 0.77± 0.73 | 0.93 |
| Pierids | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 2 | 1 | 4 | 1 | 0 | 0 | 11 | 0.85± 1.14 | 1.03 |
| *I.scuttellaris* | 0 | 0 | 2 | 2 | 3 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 13 | 1.00± 1.00 | 1.21 |
| *Dipteran* sp. | 0 | 0 | 0 | 0 | 2 | 3 | 1 | 3 | 1 | 0 | 0 | 0 | 0 | 10 | 0.77± 1.17 | 0.93 |

(2011), a total of 17 species belonging to 10 families of four orders *viz.*, Hymenoptera, Lepidoptera, Diptera and Coleoptera were recorded foraging in bitter gourd. Among these, *T.iridipennis* Smith, *H.gutturosus* Vachal and *A.florea* F. were the most frequent. Mary *et al.* (2012) showed that species of pollinators of bitter gourd included Honeybees (*A.mellifera*), *Plebeian hildebrandti*, *Lasioglossum* sp. and *Carpenter* bees (*Xylocopa* spp.).

## Abundance of flower visitors in bitter gourd

**Visual counting method :** The data on visual counts of flower visitors with respect to their abundance in bitter gourd in all the three seasons revealed that *Apis* bees, *A.cerana* and *A.florea* were significantly larger in number and constituted nearly 65% when compared to other non-*Apis* species visiting bitter gourd flowers. Within these two *Apis* species of flower visitors, A.cerana was more abundant than *A.florea* with percent abundance of 50.42 when compared to *A.florea i.e.*, 15.41, respectively (Table.2). The non-*Apis* species such as *Lasioglossum* spp. and *T.irridipennis* were found to be more active with per cent abundance of 10.83 and 9.34, respectively.

According to McGregor and Todd (1952) bee foraging activity begins on the flower shortly after it opens, reaches a peak at about 11.00 h and ceases by about 17.00 h in cucurbit crops. In present study, *Lasioglossum* spp. and *T.irridipennis* increased with increase in floral abundance across flowering period of the crop. The visual counting method was the most reliable to record species and abundance of flower visitors for pollination biology studies.

**Bee bowl collection and yellow pan trap method :** The results from bee bowl and yellow pan collection showed that *A.cerana*, *A.florea*, *Lasioglossum* sp. 1, *Lasioglossum* sp. 2, *Lasioglossum* sp. 3, *Braunsapis* sp., *Nomia* sp., *C.hieroglyphica*, *C.binghami*, syrphids and other Dipterans were abundant with over all mean of 2.37±1.99, 1.67±1.45, 1.08±0.86, 1.67±1.45, 0.75±0.47, 0.83±0.49, 0.96±0.60, 0.79±0.49, 0.67±0.41, 0.25±0.27 and 3.42±3.46, respectively in kharif-2014 (Table.3).

The different colours of bee bowls and yellow pan traps were evaluated to record attraction for flower visitors. Among the traps, yellow pan trap collected highest number of bees with a mean collection of 2.70±2.77 followed by yellow coloured bowl with a mean collection of 2.05±1.37, respectively. The blue and white coloured bowls recorded with a mean collection of 1.02±0.68 and 1.52±0.88 respectively. The green and gray coloured bee bowls attracted least number of flower visitors (Table.3). The present study is in agreement with Revanasidda (2015) who also recorded that *A.florea* and *A.cerana* and non-*Apis* species like *Ceratina hieroglyphica*, *C.binghami*, *Lasioglossum* spp. and *Nomia* sp. in abundance with bee bowls and conformed that yellow, blue and white color bowls were more efficient for pollinator collection than green and grey ones.

**Table. 3 Abundance and flower visitors in bitter gourd (bee bowl collection) during *Kharif*-2014.**

| Pollinator sp. | Bee bowl colour | | | | | | Overall |
|---|---|---|---|---|---|---|---|
| | Yellow | Blue | Gray | White | Green | Yellow pan | Mean±SD |
| *A.cerana* | 4.50±3.51 | 1.25±0.96 | 0.50±0.58 | 2.50±1.29 | 0.50±1.00 | 5.00±4.08 | 2.37±1.99 |
| *A.florea* | 3.50±2.65 | 1.00±0.82 | 0.00±0.00 | 1.75±1.26 | 0.50±0.58 | 3.25±3.40 | 1.67±1.45 |
| *Lasioglossum* sp.1 | 1.75±2.22 | 1.25±0.50 | 0.00±0.00 | 1.75±0.50 | 0.00±0.00 | 1.75±2.22 | 1.08±0.86 |
| *Lasioglossum* sp.2 | 3.50±2.65 | 1.75±0.50 | 0.50±0.58 | 1.00±0.82 | 0.00±0.00 | 3.25±2.06 | 1.67±1.45 |
| *Lasioglossum* sp.3 | 1.00±1.15 | 0.50±0.58 | 0.25±0.50 | 1.25±0.50 | 0.25±0.50 | 1.25±1.50 | 0.75±0.47 |
| *Braunsapis* sp. | 1.25±1.26 | 1.00±0.82 | 0.50±0.58 | 0.50±0.58 | 0.25±0.50 | 1.50±1.00 | 0.83±0.49 |
| *Nomia* sp. | 1.25±0.96 | 0.75±0.50 | 0.00±0.00 | 1.75±0.96 | 0.75±0.50 | 1.25±0.96 | 0.96±0.60 |
| *C.hieroglyphica* | 1.25±0.50 | 0.75±0.50 | 0.00±0.00 | 1.00±0.82 | 0.50±0.58 | 1.25±0.50 | 0.79±0.49 |
| *C.binghami* | 0.75±0.50 | 0.50±0.58 | 0.00±0.00 | 1.25±0.96 | 0.75±0.50 | 0.75±0.50 | 0.67±0.41 |
| Syrphids | 0.50±1.00 | 0.00±0.00 | 0.00±0.00 | 0.50±1.00 | 0.00±0.00 | 0.50±1.00 | 0.25±0.27 |
| *Dipteran* sp. | 3.25±2.50 | 2.50±0.58 | 0.50±1.00 | 3.50±1.29 | 0.75±0.96 | 10.00±3.65 | 3.42±3.46 |
| **Total** | **22.50** | **11.25** | **2.25** | **16.75** | **4.25** | **29.75** | |
| **Mean±SD** | **2.05±1.37** | **1.02±0.68** | **0.20±0.25** | **1.52±0.88** | **0.39±0.30** | **2.70±2.77** | |

Each cell carries mean of 4 sampling days representing 4 weeks.

**Table. 4 Shannon-Weaver index of diversity (H) for flower visitors during different weeks representing different percent flowering during *Kharif*-2014**

| % flowering | Pollinators sp. | | | | | | | | "H" value |
|---|---|---|---|---|---|---|---|---|---|
| | ***A.cerena*** | ***A.florea*** | ***T.iridipennis*** | ***Lasioglossum* sp.** | ***Ceratina* sp.** | ***Braunsapis* sp.** | ***Nomia* sp.** | ***I.scuttellaris*** | |
| 25% | 399 | 91 | 89 | 66 | 14 | 11 | 10 | 8 | 0.58 |
| 50% | 476 | 138 | 90 | 98 | 17 | 28 | 16 | 10 | 0.61 |
| 75% | 540 | 165 | 100 | 116 | 22 | 51 | 28 | 13 | 0.65 |
| >90% | 637 | 412 | 119 | 128 | 47 | 58 | 42 | 36 | 0.68 |

Mean of four sampling days.

The bee bowl and yellow pan trap collection may be suitable to record the species of the flower visitors that are missed from visual counting. Among different traps evaluated to record flower visitors, yellow pan trap followed by yellow bee bowl were more efficient.

**Diversity of flower visitors :** The data on the abundance of bee species and their diversity in different times of day and in different weeks were used to calculate the Shannon-Wiener Diversity Index. In kharif-2014, the maximum pollinator diversity remained same between 08.00 to 14.00 h except between 06.00 to 07.00 h and later the activity decreased gradually.

Diversity was also calculated for flower visitors across different weeks representing different flowering percentage. The diversity was less in first week but later increased with increase in per cent flowering. The "H" values at 25, 50, 75 and >90 percent flowering during kharif-2014 seasons were 0.58, 0.61, 0.65 and 0.68, respectively (Table.4).

The diurnal and seasonal activity of the most frequent and reliable floral visitors varied during the day and the season. The probable reason may be environmental variation in temperature, light intensity, wind speed and relative humidity, as well as plant characteristics including floral structure and the spatial and temporal arrangement of flowers. The temporal variation in the production of the reward (nectar and pollen) also influences the rate of visitation. Differences in visitation rates among pollinators are probably related to both pollinator efficiency and effectiveness.

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