NEST ARCHITECTURE AND FORAGING BEHAVIOR OF *Ceratina viridissima* (Dalla Torre)

by

Shallu Choudhary

(J-19-M-630)

A Thesis submitted to

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MASTER OF SCIENCE IN AGRICULTURE
ENTOMOLOGY

Division of Entomology

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Main Campus, Chatha, Jammu – 180009

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CERTIFICATE-I

This is to certify that the thesis entitled **"Nest Architecture and Foraging Behavior of *Ceratina viridissima* (Dalla Torre)"** submitted in partial fulfillment of the requirement for the degree of **Master of Science in Agriculture (Entomology)** to the Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, is original work and has similarities with published work not more than minor similarities as per UGC norms of 2018 adopted by the University. Further the level of minor similarities has been declared after checking the manuscript with Urkund software provided by the university.

The work has been carried out by **Ms. Shallu Choudhary**, under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma. It is further certified that help and assistance received during the course of thesis investigation have been duly acknowledged.

Dr. Devinder Sharma
(Major Advisor)

Place: Jammu

Date: 29-10-2021

Head of the Division

Dean

CERTIFICATE-II

We, the members of the Advisory Committee of **Ms. Shallu Choudhary,** Registration No. **J-19-M-630**, a candidate for the degree of **Master of Science in Agriculture (Entomology)**, have gone through the manuscript of the thesis entitled **"Nest Architecture and Foraging Behavior of *Ceratina viridissima* (Dalla Torre)"** and recommend that it may be submitted by the student in partial fulfillment of the requirements for the degree.

Dr. Devinder Sharma
Assistant Professor (Entomology)
(Major Advisor & Chairman
Advisor Committee)

Place : Jammu

Date : 29-10-2021

Advisory Committee Members

Member from major subject

Dr. R.K Gupta
Professor
Division of Entomology

Member from minor subject

Dr. R.K Salgotra
Coordinator
School of Biotechnology

Member of supporting subject

Dr. B. Brahma
Associate Professor
Division of LPM, F.V,Sc, R.S Pura

Dean's nominee

Dr.R.K Samnotra
Professor
Division of Vegetable Science

CERTIFICATE-III

This is to certify that the thesis entitled **"Nest Architecture and Foraging Behavior of *Ceratina viridissima* (Dalla Torre)"** submitted by **Ms. Shallu Choudhary,** Registration No. **J-19-M-630** to the Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu in partial fulfillment of the requirements for the degree of **Master of Science in Agriculture (Entomology)** was examined and approved by the Advisory committee and external examiner(s) on **24.11.2021**

Dr. D.P. Abrol
Ex-Dean FoA
SKUAST-Jammu
Chatha.
(External Examiner)

Dr. Devinder Sharma
Assistant Professor
(Major Advisor)
Division of Entomology

Dr. R.K Gupta
Professor & Head
Division of Entomology

Dean, FOA, SKUAST-J

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(Shallu Choudhary)

ABSTRACT

Title of Thesis	:	**Nest architecture and foraging behavior of *Ceratina viridissima* (Dalla Torre)**
Name of the Student	:	Shallu Choudhary
Registration No.	:	J-19-M-630
Major Subject	:	Entomology
Name and Designation of Major Advisor	:	Dr. Devinder Sharma, Assistant Professor (Division of Entomology)
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ABSTRACT

The present study entitled **"Nest architecture and foraging behavior of *Ceratina viridissima* (Dalla Torre)"** was conducted at the experimental area of the Division of Entomology, SKUAST-J to ascertain the nest architecture, foraging behavior and morphometric traits of *Ceratina viridissima*. Thirty nests of each selected planting material viz., *Rosa* spp., *Saccharum spontaneum*, and *Saccharum bengalense* were utilized to investigate the nesting architecture of *Ceratina viridissima*. Analysis of variance (Tucky test) revealed the presence of significant difference among the nesting parameters viz., length of nest, width of nest entrance, length of chamber, breadth of chamber, number of chambers, number of adult bees, number of larva and number of pupa. *Saccharum spontaneum* was prefered by small carpenter bees as a nesting material over the *Rosa* spp and *Saccharum bengalense*.

Foraging behavior of small carpenter bees was observed on selected crops such as *Ocimum sanctum and Trifolium alexandrinum* in the month of march, 2021 by recording the observations viz., time spent on flowers (s) and number of flowers visited per minute by *Ceratina viridissima*. Study also confirmed that *Ceratina viridissima* starts its foraging activity at morning hours (9:00 am) and return back to their nests at evening hours (5:30 pm).

Foraging activity of small carpenter bees in relation to abiotic factors recorded indicated the strong association of foraging activity of *Ceratina viridissima* with daily sunshine hours (h) and temperature (°C) while as relative humidity and evaporation was observed to have non significant association with foraging behavior of small carpenter bees.

Twenty samples of small carpenter bees were observed under Leica microscope for morphometric studies for estimation of dimensions of various body parts of *Ceratina viridissima.*

The present study will help in conservation of *Ceratina viridissima* through provisioning of alternative nesting structure to facilitate pollination in crops.

Keywords: *Ceratina viridissima*, Foraging behavior, Morphometric study, Nest architecture and Abiotic factors

Signature of Major Advisor

Signature of Student

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ABBREVIATIONS

%	:	Per cent
^{0}C	:	Degree Celsius
ANOVA	:	Analysis of variance
mm	:	Milli meter
hrs	:	Hours
s	:	Second
min	:	Minute
et al.	:	Et alia meaning ‘and others’
Max	:	Maximum
Min	:	Minimum

CHAPTER 1

INTRODUCTION

Pollination is an important process in the plants for flowering and seed setting. Many agricultural and horticultural crops are pollinated by Apis and non-Apis pollinators. Apis pollinator like honey bees helps in pollination of most of the crops important for agricultural purposes, give economic benefits to farmers. Besides pollination, honey bees also give economic products like honey, wax and pollen. Nowadays Apis pollinators are facing survival problems like longterm effects of pesticides that are frequently used by farmers in their field, climatic change also affects the honey bees, distruction of native habitat for mankind affects the Apis pollinator. These problems directly or indirectly disrupts the pollination process in agricultural crops and leads to decrease in crop yield.

Non-Apis pollinator are equally important as Apis pollinator due to their vital role in pollination. These non-Apis pollinator include many bees like bumblebee, Ceratina, Megachile etc. These bees helps in pollination of various agricultural and horticultural crops. According to the researchers these bees are relatively less affected from the toxicity of pesticides, thus facing less survival problems as compared to the Apis pollinators, also there is no need to manage the colonies of non-Apis pollinators. These bees use native habitat around the useful crops as they live in dead hard wood. In many countries, the non-Apis pollinator nests are becoming famous among farmers speacially in green house crops.

Nowadays, the establishment of nests of non-Apis pollinator become a better alternatives for farmers for pollination of their crops. There are many genera of non-Apis pollinator among which two important generas are large carpenter bees (*Xylocopa* spp.) and small carpenter bees (*Ceratina* spp.). Small carpenter bees also called *Pithitis* spp., having blue metallic and green colour. These bees live in dead hardwood of plants and they chew out the pith of the plant and make linear nests. Small carpenter bees are also called solitary bees because these bees gaurd their respective nests and take care of their young ones alone.

Life cycle of small carpenter bees is reported to be 28-32 days from egg to adult (Ali *et al*., 2016). The adult female bee lays eggs on pollen masses in different

cells of the nest, the female lays one egg on pollen mass in different chambers of the nest. Fully grown larvae have consumed their entire pollen mass and are round and fat, whereas prepupae are post-defecatory and longer and skinnier than fully grown larvae. Prepupae develop into white-eyed pupae, after which their eyes darken to pink, red, brown, and finally black. Following the black-eyed stage, the entire body becomes pigmented, with pigmentation described in terms of the proportion of black integument. Pupae moult into milky-winged adults after full pigmentation (Rehan and Richards 2009).

It is widely distributed with more than 350 species all over the world (Ali *et al*., 2016). The morphometric estimates aids in quantitative characterization of the body of the organism which is done for the identification of the species, for comparative study of specimen and for male and female distinguishment. Many researches were carried for investigating the nesting biology of the *Ceratina* spp. all over the world, in some countries there is commercialization of the nesting structures among farmers for facilitate the pollination process in their crops. In India many studies have carried on the nesting biology of *Ceratina* spp. with the aim to provide better alternatives for farmers to increase their crop yield. In the light of the foregoing, the present study was conducted with the following objectives:

- To study the nest architecture of *Ceratina viridissima*
- To study the foraging behavior of *Ceratina viridissima*
- To study the morphometric of *Ceratina viridissima*

CHAPTER 2

REVIEW OF LITERATURE

The following review discusses nest architecture of *Ceratina viridissima*, foraging behaviour and morphometric studies. The relevant and available literature on the various aspects of the current investigation has been reviewed briefly and is presented under the appropriate headings below.

2.1. Nest architecture of *Ceratina viridissima*

Malaipan and Orostrirat (1992) revealed that small carpenter bees, *Ceratina* spp. were observed to choose the twigs prepared for nesting site. They studied that *Pithitis smaragdula* choosed mulberry, sesbania, eupatorium and lantana. No size preference in length on diameter of twig pith were found between the species on which they studied.

Rehan and Richards (2009) studied the life history and nesting biology of a common eastern North American species, *Ceratina* (Zadontomerus) *calcarata* Robertson using pan trap and nest collection in southern Ontario and reported that nest founding and provisioning occurred throughout the spring. The life cycle from egg to adult was 46 days with an average of 6.9 offspring per nest.

Rehan *et al*. (2009) described the nesting biology and social behaviour of four Ceratina species that have been described taxonomically but not behaviourally. They described the recurring patterns of maternal care, maternal longevity and nest protection in four tropical ceratinines *Ceratina* (Ceratinidia) *accusator* Cockerell, *C.* (Ceratinidia) *nigrolateralis* Cockerell, *C.* (Neoceratina) *dentipes* Friese, *C.* (*Pithitis*) *smaragdula* Fabricius. They collected nests from various locations and reported that all four species formed single linear burrows in pithy stems with different nest dimensions. *Ceratina nigrolateralis* had exceptionally long nest burrows that left about three-quarters of the nest's length as an entrance gallery according to this study. The three remaining species, on the other hand, dug shorter nesting burrows and left galleries about half the length of their nest.

Vickruck (2010) collected nests and pan traps to describe and compare the nesting biology and life histories of the three most common species, *Ceratina dupla*, C. *calcarata* and the newly discovered Ceratina near dupla. *Ceratina dupla* and C.

near dupla both nested more frequently in teasel (*Dipsacus* sp.) in the sun, occasionally in raspberry (*Rubus* sp.) in the shade and never in shady sumac (*Rhus* sp.) whereas *C. calcarata* nested most frequently in raspberry and sumac (shaded) and only occasionally in teasel (sunny). Ceratina near dupla differed from both *C. dupla* and *C. calcarata* in that it appeared to be partially bivoltine, with some females establishing nests early in the season and then again late in the season. He looked into the interactions and potential nest competition between *C. dupla* and *C. calcarata*.

Hongjamrassilp and Warrit (2014) studied the nesting biology of the Oriental large carpenter bee, *Xylocopa*. They collected nests from the site in order to dissect and measure the external and internal nest architecture, as well as to examine the pollen composition of pollen masses. They revealed that *X. nasalis* builds linear unbranched nests with the nest entrance mostly at the open end of the bamboo culms, as well as the nest length (25.40 ± 6.95cm), branch diameter of the nest entrance (17.94 ± 6.00mm) and maximum number of provisioned cells (8).

Rehan *et al*. (2015) investigated social nesting behaviour in three Neotropical *Ceratina* (Ceratinula) species: *Ceratina buscki, Ceratina tricolour* and *Ceratina zeteki*. They gathered nests from the stems of Bougainvillea, specifically *Ceratina tricolour*. This study provided the first proof of social nesting in three Neotropical species. They confirmed that all species had similar nest dimensions ranging from 40 to 65 mm long and 2.5–3.0 mm wide and that these Ceratina species reused nests.

Ali *et al*. (2016) investigated the nesting biology of the *Ceratina smaragdula*. They collected nests from two different locations, observed the nests and recorded nest details and times on a variety of floral species, with bees preferentially nesting in Ravenna grass wooden stalks (*Saccharum ravennae* L.; Poales: Poaceae).They measured the average length of the nest (12.73 ± 6.51cm), the diameter of the entrance (4.19 ± 0.41mm), the number of cells (1-7) and the average cell length (8.48 ± 4.13mm).

Yogi and Khan (2016) investigated the nesting biology of *Ceratina propinqua* and *Ceratina simillima* in order to learn more about these bees' nesting habitats by conducting surveys at potential nesting sites on a weekly basis. They reported that both species built linear nests in the soft pith and that *C. propinqua* nests had a series of brood cells that were frequently separated by empty cells (the oldest cell below),

whereas *C. simillima* nests did not. They looked at the orientation of *C. propinqua* prepupae, pupae and preadults which was downward towards the base of the nesting stem and *C. simillima* pupae, which was upward towards the nest entrance.

Ali *et al*. (2016) studied large carpenter bees, which are promising pollinators for many agricultural crops. They dissected the nests to examine both nest architecture and nesting biology of the species and revealed that they preferentially nest in dead wooden stems of Poplar (*Populus deltoides*) and Sesbania (*Sesbania bispinosa*), confirming that this study is also useful in using large carpenter bees for pollination.

Kaliaperumal (2019) studied the nest structure, development and natural enemies of *Ceratina hieroglyphica* Smith, a stem nesting bee that colonises cashew trees in hilly terrain, at the ICAR Directorate of Cashew Research in Puttar, Karnataka. They collected the nests and documented the nesting details, such as average nest length ranged from (2.5-10.8cm), the entrance diameter (3.0-3.5mm), the number of cells (1-14), the average cell length (7-8mm) and the number of adult (1-6).

Udayakumar and Shivalingaswamy (2019) studied the *Ceratina binghami*, a small carpenter bee, (Xylocopinae: Apidae). They described *C.binghamis* nesting behaviour in pithy stems of *C. pulcherrima* and they were observed that nests were unbranched, with an average length of (8.04 ± 1.93 cm) and an entrance hole that was (1.26 ± 0.11 cm) wide. Each nest contained (6-7 cells), with an average length and breadth of (1.0cm and 1.0cm). This study indicating that in-situ conservation and use of these bees in agricultural crop pollination is possible.

Sneha Latha *et al*. (2020) conducted research at the Madurai Agricultural College and Research Institute. For this study 29 nests were collected from Crotons, *Codiaeum* spp., Yellow bell, *Tecoma* spp., Peacock flower, *Caesalpinia pulcherrima*, Copper pod tree, *Peltophorum pterocarpum* and Rose. They reported that nests are linear and partitioned with chewed straw. Among these, *Peltophorum pterocarpum* was the most preferred host. The diameter of the nest entrance, as well as the length and width of the nests, were measured to be (0.36 ± 0.06 cm), (11.59 ± 4.35 cm) and (0.36 ± 0.06 cm) respectively.

Mikal *et al*. (2021) described the nesting cycle of *C. Nigrolabiata*. They revealed that the female is capable of long-term offspring protection. Although the

female can perform long-term offspring guarding, only (22%) of fully provisioned nests are guarded by a female. When provisioning is completed, the majority of nests (54%) are closed and abandoned, while others (24%) are orphaned before provisioning is completed. They also confirmed that *C. nigrolabiata* is unique among bees due to its biparental behaviour, but it also has unusual nesting biology traits among *Ceratina* bees, such as fast offspring development in comparison to provisioning rate and a high proportion of closed and abandoned nests by mother.

2.2. Foraging behavior of *Ceratina viridissima*

Daly *et al*. (1970) reported that *Pithitis smaragdula* (F.) is a bright green, small carpenter bee that is widespread in the eastern region and is known to pollinate economically important plants, particularly legumes and cucurbits. They observed the foraging behavior of the bees and confirmed that one or more generations of bees had been reared and that *Trifolium repens* L. had begun visiting in search of pollen. Few natural enemies, low food competition, high competition for nesting sites and cooler- drier climate than the native habitat were all considered important factors in the colony's establishment.

Raju (2008) studied the *Pithitis binghami's* foraging behavior in various plant species for food. According to the findings of this study, *Pithitis binghami* feeds on white flowers and its sex organs are exposed, allowing it to consume an abundance of pollen and nectar.

Zurbuchen *et al*. (2010) investigated maximum foraging distances in solitary bees in an experiment. They selected one endangered and two common species of varying body sizes, all of which restrict pollen foraging to a single plant genus, were successfully established in a landscape devoid of their specific host plants. Females were forced to collect pollen on potted host plants that were gradually moved away from fixed nesting stands. They found that small *Hylaeus punctulatissimus* had a maximum foraging distance of 1100 m,the medium *Chelostoma rapunculi* had a distance of 1275 m and the large *Hoplitis adunca* had a distance of 1400 m. They revealed that a close proximity of nesting and foraging habitat within a few hundred metres is critical for the survival of these specie’s populations and that threshold distances at which half of the population stops foraging are a more

meaningful parameter for conservation practise than species-specific maximum foraging distances.

Kidokoro and Higashi (2010) studied the food habits of the solitary bee *Ceratina flavipes*, observing its foraging behaviour and identifying the pollen grains they collected. They reported that *C. flavipes* collects pollen from specific species but visits multiple flowering species. They found no significant interaction between seasonal pollen availability and bee preferences when pollen balls were created. These findings suggest that *C. flavipes* has flower constancy and thus the generalist pollinator *C. flavipes* could function as a specialist pollinator.

Rasmussen *et al*. (2010) studied that a single bee species will never visit all of the flowers in a given area. Floral morphology or flowering phenology constraints may prevent them from doing so, but what's more interesting is that most bees prefer pollen from specific plant species. They looked into the floral resources preferred by three different bee species: *Ceratina*, *Halictus*, and *Bombus.* They reported that pollen loads brought back to the nest by the small carpenter bee (*Ceratina flavipes*) and also found that preference for specific pollen sources persisted even when the plant was rare. As a result of their research, they discovered the phenomenon known as flower constancy.

Raju and Reddi (2015) reported that carpenter bee or specie of xylocopa are prominent members of the Indian bee fauna. They can be found all year, foraging during the day and only very rarely at night. They revealed that carpenter bees provide an excellent service to the plants they pollinate by foraging for flowers. They confirmed that carpenter bees are devoted to flowering plants and have a significant impact on cross pollination.

Rehan *et al*. (2015) investigated the relationship between foraging behavior and social behaviour in the solitary bee *Ceratina australensis*. To ensure that no bees were out foraging, they collected natural solitary and social nests from dead broken fennel (*Ferula communis)* stems in the field at dawn and dusk. They compared the brains of solitary females who forage and reproduce but do not interact socially to those of social individual while controlling for age, reproductive status and foraging experience. They confirmed that dominance and foraging effects were additive, with dominant social primary foragers having larger mushroom body volumes than solitary

foragers and solitary foragers having larger mushroom body volumes than non-foraging social secondary guards.

Ali *et al*. (2016) studied the foraging behaviour of large carpenter bees, which are promising pollinators for a variety of agricultural crops. They investigated foraging activities in north western Pakistan, which is the extent of the species' natural distribution, because these species are potentially important pollinators of cucurbit crops and some agricultural crops in this region. They reported that individuals foraging on a variety of cultivated crops near the nesting area. Most importantly for the region, they documented the species that visited the flowers of some important vegetables, such as cucurbits and okra. They found that bees began flying in the early morning around (6.59 am ± 36 min) and returned from their first flight after an average of (12.83 ± 1.77 min) with pollen and that they ended their daily foraging bouts in the late afternoon around (5.55 pm ± 25 min) and spent an average of 55.50 ± 15.58 s on flower.

Ali *et al.* (2016) investigated the foraging behavior of *Ceratina smaragdula*, which visited a variety of floral resources. They revealed individuals foraging on a variety of cultivated crops, including alfalfa and oil seed rape, near the nesting area. They documented the species that visited the flowers of three important vegetable crops: okra, sponge gourd and pumpkin. During the investigation period, they found that bees began flying in the early morning around (6:54 a.m.± 23 min) and spent an average of (25.4 ±7.1s) on each flower, finishing their daily foraging bouts in the late afternoon around (4:47 p.m.± 35 min).

Painkra *et al*. (2017) conducted research on Apis-pollinator species at various migratory sites in northern India to investigate the effect of various weather parameters such as temperature, relative humidity, sunshine hours and rainfall on Apis-pollinator foraging behavior. They found that maximum temperature had a significant and positive correlation with pollen area, as well as that weather parameters influence bee strength and brood area.

Sharma and Abrol (2017) investigated the foraging behavior of *Amegilla zonata* in relation to various environmental factors in *Ocimum kilimandscharium*. They reported that its foraging activity was significantly affected by abiotic factors and that it visited this crop frequently.

Mikat *et al*. (2017) reported that the *Ceratina calcarata* has dual-phase pollen provisioning. They studied the provisioning behaviour in *C. calcarata* to investigate patterns of maternal investment and foraging dynamics during the breeding season. They revealed that during the second provisioning period, the foraging behavior of worker-like daughters were comparable to mothers in terms of length of foraging trip and handling time.

Udayakumar and Shivalingaswamy (2019) they studied the foraging activity of the *Ceratina binghami*, they found that these bees started their foraging activity during morning hours approximately between 6.45 to 7.15 am and ended during the late evening hours of 4.50 to 5.15 pm. This study revealed that the conservation of these bees utilises for the pollination of many agricultural crops.

Suneetha and Soloman (2019) investigated the foraging behavior of carpenter bees, *Xylocopa latipes* and *Xylocopa pubescens* in *Moringa oleifera*, an economically important tree species that blooms and fruits almost all year. They revealed that these bees are quick fliers who visit as many flowers as they can in the shortest amount of time, implying that they are important for both self and cross pollination. They found that the anther dehiscence and anthesis schedules are perfectly tailored for pollination by carpenter bees during the day.

2.3. Morphometric studies of *Ceratina viridissima*

Borsuk and Olszewski (2010) examined and compared morphometric characteristics in Buckfast bees. The characteristics of the foreign bee were compared to those of the Caucasian. The photographs were taken with a digital camera attached to an Olympus SZX 12 microscope. The photographs were analysed using the image analysis software MultiScanBase. To aid in the calibration of the MultiScanBase software, millimetre paper was taped to each part of the insect's body. Pure-bred Buckfast and Caucasian worker bees were used in the study. They measured traits such as proboscis length, venation for determining the cubital index of the right wing and the width of tergite III and IV. They counted the right hindwing hooks and the rows of pollen brush hairs on the third pair of leg’s right leg. The length of the proboscis was found to be the most deviant from the Caucasian breed standard, while the other morphometric traits did not differ from the standard.

Pinto *et al*. (2015) investigated the relationship between the mother's size and the size of her progeny in the oil-collecting bee *Tetrapedia diversipes* (Apidae). A digital camera and a stereomicroscope were used to photograph the bees and the structures were measured using Gimp® software. They investigated the relationship between the body size of individual oil-collecting bees of the species *Tetrapedia diversipes* and the size of their brood cells in the Brazilian states of Boracéia and Ilhabela. They indicated a link between the size of these bees' bodies and the amount of food they ate. They found no statistically significant size difference between males and females. Only a weak relationship between body size and brood cell volume was found, which could be attributed to the low variation in both female and brood cell size.

Tej *et al*. (2017) studied the morphology of the stingless bee *Tetragonula iridipennis* in the Tamil Nadu districts of Coimbatore, Erode and Tiruppur. They collected adult worker bees from *T. iridipennis* feral nests in three different locations. The preserved bees were dissected under a Leica M165 stereo microscope and fourteen morphometric measurements were taken. They found that bees collected in the Coimbatore district were larger (Mean of head length = 1.53, head width = 1.76, antennal length = 1.87, hind leg length =3.46, forewing length = 4.00 and hind tibial length =1.60 mm) than those collected in the other two districts also, the Erode district bees were small (Mean head length = 1.23, head width = 1.62, antennal length = 1.67, hind leg length = 3.26, forewing length = 3.32 and hind tibial length = 1.31 mm).

Parmar (2019) described the immature stages *Ceratina smaragdula*, he found nests in crop fields between Jodhpur and Pali district. The nests were collected at dusk and the openings of the nests were closed with cotton to prevent adult bees from escaping. After a week, the nests were brought to the laboratory and opened. Microscopic observations on their morphology were also made using an olympus stereozoom binocular microscope. Micrometers were used to take measurements and camera lucida was used to draw the figures. He observed that larvae were slender with distinct inter-segmental lining and had setae on the head capsule. He also described the resemblance of pupa with the adult in taxonomic characters of identification. The pupal characteristics that are specific to pupae include presence of spines and projections arising from various body parts.

Oliveria *et al.* (2020) described a new species of small carpenter, genus *Ceratina* (Ceratinula) Moure, by using the type specimen *C. manni* and provided an identification key for the *Ceratina (*Ceratinula) species recorded for Brazil in Moure's catalogue of Neotropical bees. Specimens were studied and photographed using a Leica M165C stereomicroscope coupled to a Leica DFC295 digital camera, containing the program LEICA application suite 4.1. Interactive Measurements, Montage. Measurements are given in millimeters and taken at the greatest width or length of structures.

CHAPTER 3

MATERIAL AND METHODS

Experiments were conducted under field and in laboratory conditions to find out the nest architecture, foraging behavior and morphometric studies of *Ceratina viridissima.* Experimental procedure and materials used during the research work are given below in a summarized form.

3.1. Nest Architecture of *Ceratina viridissima*

Nest architecture were studied in the research farm, Faculty of Agriculture main campus Chatha. Thirty nests of different planting material (*Rosa* spp., *Saccharum spontaneum* and *Saccharum bengalense*) were chosen for testing the architecture with ten replications of each nest. During evening hours, when adult bees were inside the nest, the nest was collected and one end was plugged with cotton. Following that, nests were given a longitudinal cut with a knife and cutter, taking great care not to destroy the nests. Nesting parameters were recorded with the help of digital vernier caliper and using the software SPSS 16, descriptive statistics were used to analyse all of the data and the values were expressed as mean and standard deviation for the following parameters:

3.1.1 Length of Nest (mm)

3.1.2 Width of Nest entrance (mm)

3.1.3 Length of chamber (mm)

3.1.4 Breadth of chamber (mm)

3.1.5 Number of chamber

3.1.6 Number of adult bees

3.1.7 Number of larva

3.1.8 Number of pupa

3.2. Foraging Behavior of *Ceratina viridissima*

Foraging behavior of *Ceratina* viridissima was studied in the research farm Faculty of Agriculture at main campus Chatha. Nests of different planting material were aligned in the iron structure, randomly fifteen nests were selected for recording

initiation time and cessation time of foraging activity of the bee at different hours of the day with the help of camera fitted at nesting site. *Ocimum sanctum* and *Trifolium alexandrinum* were observed for the activity of *Ceratina viridissima* in the month of march, 2021. Five plants were randomly selected from both the crops to record the observations on parameters given below:

- Time spent by *Ceratina viridissima* on flowers
- Number of flowers visited per minute by *Ceratina viridissima*

3.3. Morphometric study of *Ceratina viridissima*

Morphometric study of *Ceratina viridissima* were carried under laboratory conditions at division of Entomology, SKUAST-J main campus Chatha. Twenty specimen of *Ceratina viridissima* was prepared by collecting the bees from the field crops with the help of net and killing bottle, after that the sample was preserved and pinned in the insect box. The morphometric study was done with the help of Leica microscope which gave the measurement of body dimensions. Following observations were recorded:

3.3.1 Length of body (mm)

Length of body was measured from dorsal side of head to last tergum of abdomen.

3.3.2 Length of head (mm)

Length of head was measured from widest part of the head.

3.3.3 Breadth of head (mm)

Breadth of head was measured from lateral sides of paraoccular regions.

3.3.4 Length of antenna (mm)

Length of antenna was measured from basal scape to the last flagellum.

3.3.5 Length of forewing (mm)

Length of forewing was measured from basal to posterior margin of wing.

3.3.6 Breadth of forewing (mm)

Breadth of forewing was measured from subcosta to cubitus.

Plate No. 3.1: Investigating nest architecture and taking observations for various nest parameteres

Plate No. 3.2: Investigating foraging activity of *Ceratina viridissima*

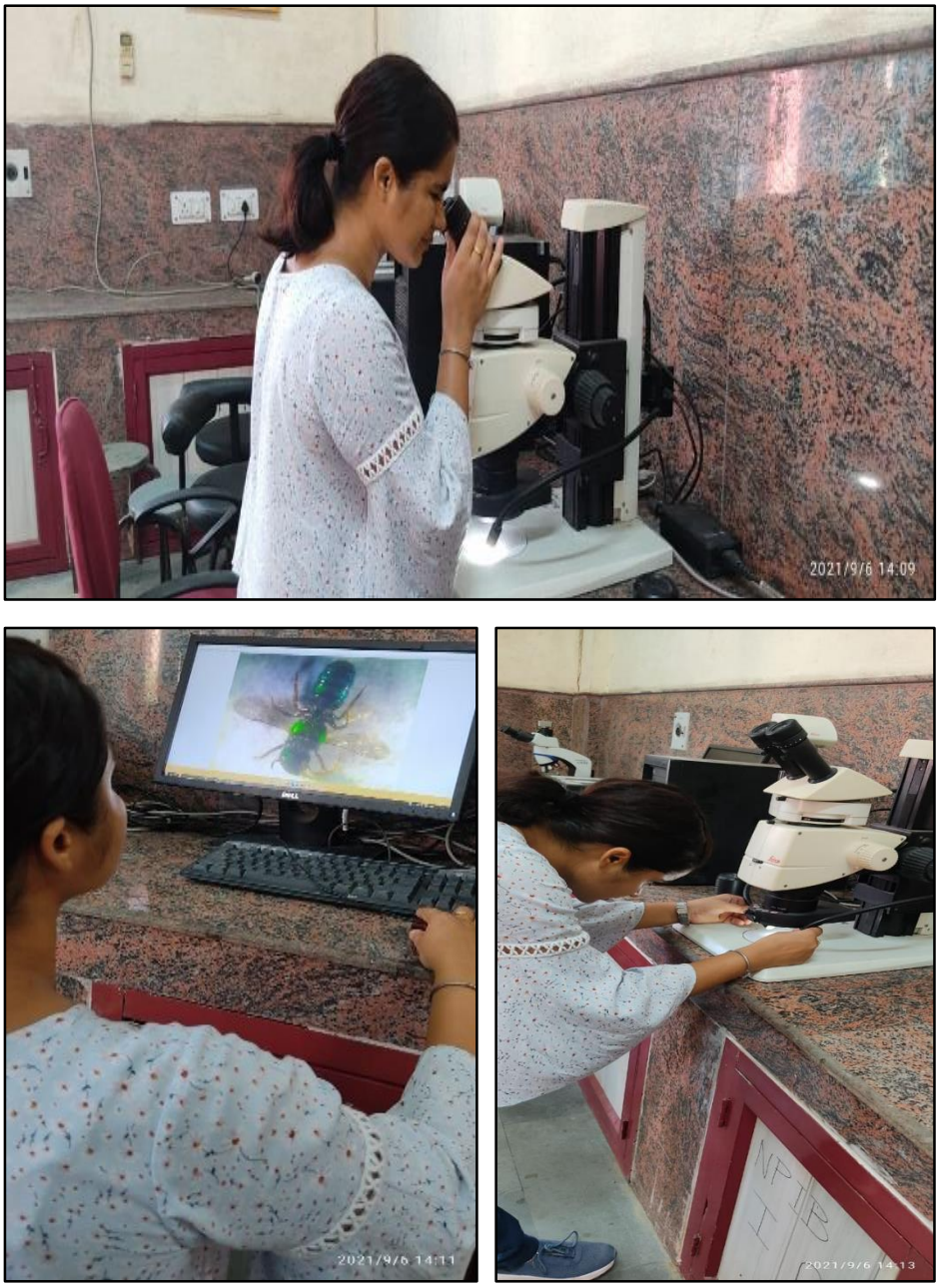


Plate No. 3.3: Morphometric study using Leica microscope

3.3.7 Length of hindwing (mm)

Length of hindwing was measured from basal to posterior margin of wing.

3.3.8 Breadth of hindwing (mm)

Breadth of forewing was measured from subcosta to cubitus.

3.3.9 Length of three pair of legs (mm)

Length of three pair of legs was measured from coxa to tarsus.

3.3.10 Length of proboscis (mm)

Length of proboscis from clypeus to flabellum

3.4. Statistical analysis

Data collected from the experimental location for studying the nest architecture of *Ceratina viridissima* in different planting material was subjected to statistical analysis using SPSS-16 software. Mean value and standard error of nesting parameters was computed at 5 per cent level of significance using a one way analysis of variance (ANOVA) and post hoc data analysis Tukey HSD test. The effects of abiotic factors like temperature, relative humidity, sunshine and evaporation on the foraging behavior was estimated with the help of correlation coefficient by using the software O.P. STAT. The strength of association between the abiotic factors and foraging behavior was computed with the help of scatter diagram in which R^2 (Square root of correlation coefficient) in percentage gave the determination of the strength of the correlation between abiotic factors and foraging activity of the *Ceratina viridissima.*

CHAPTER 4

RESULTS

Ceratina viridissima is an important non-Apis pollinator that pollinates many agricultural and horticultural crops. It will serve as the excellent alternative to the Apis pollinator especially honey bees. In order to exploit these non Apis pollinator to boost the production of agricultural crops, there is need to study their nesting structure, foraging behavior and morphometric parameters. Experimental results of present study is comprehensively described below through appropriate tables and figures.

4.1 Nesting Architecture of *Ceratina viridissima*

Analysis of variance presented in the (Table 4.1) revealed the significant variability between the nesting parameters. All the nesting parameters of *Saccharum spontaneum* (Sarkanda) were significantly different from the *Saccharum bengalense* (kae) and *Rosa* spp. However, the width of the nest entrance had no significant difference across all nesting materials.

4.1.1 Length of nest (mm)

The nests were opened carefully starting from the entrance hole giving a longitudinal cut by using sharp Knief. Following the linear split of the nest, length was measured with the help of digital vernier caliper. Maximum mean nest length was observed for *Saccharum spontaneum* (20.77 ± 0.78mm) followed by *Saccharum bengalense* (14.38 ± 0.73mm) and *Rosa* spp. (5.38 ± 1.38mm).

4.1.2 Width of nest entrance (mm)

The width of nest entrance was measured by using digital vernier caliper before dissection. Maximum nest entrance width was observed for *Saccharum bengalense* (2.62 ± 0.07mm) followed by *Saccharum spontaneum* (2.60 ± 0.07mm) and *Rosa* spp. (2.58 ± 0.18mm).

4.1.3 Length of chamber (mm)

Experimental results further revealed that small carpenter bees make individual chamber by chewing the pith in the nest. Nests were opened by slowly and gently splitting the stem with a sharp knife, beginning at the entrance and running

parallel to the length of the branch, length of chambers were measured by using digital vernier caliper. Maximum mean length of chamber was observed for *Saccharum spontaneum* **(**16.82 ± 1.00mm) followed by *Saccharum bengalense* (8.17 ± 0.86mm) and *Rosa* spp. (2.01 ± 0.34mm) .

4.1.4 Breadth of chamber (mm)

The nests were opened carefully starting from the entrance hole giving a longitudinal cut by using sharp Knief. Following the linear split of the nest, breadth of chamber was measured with the help of digital vernier caliper. Maximum mean breadth of chamber was observed for *Saccharum spontaneum* (3.06 ± 0.22mm) followed by *Saccharum bengalense* (2.12 ± 0.50mm) and *Rosa* spp. (0.36 ± 0.24mm).

4.1.5 Number of chamber

Nests were dissected longitudinaly by using sharp knife in order to observed number of chambers manually. Experimental results further revealed maximum number of chambers was observed in *Saccharum spontaneum* (5.80 ± 0.74) followed by *Saccharum bengalense* (1.40 ± 0.03) and *Rosa* spp. (0.20 ± 0.01).

4.1.6 Number of adult bees

Nests were fully exposed by splitting the stem with the help of sharp knife. Following the splitting, number of adult bees were recorded manually. Further persual of experimental findings revealed the maximum average number of adult bees was observed in *Saccharum spontaneum* (2.80 ± 0.48) followed by *Rosa* spp. (1.30 ± 0.12) and *Saccharum bengalense* (1.10 ± 0.01).

4.1.7 Number of larva

Nests were dissected longitudinally by using sharp knife in order to observed number of larva manually. Experimental results further revealed the maximum average number of larva was observed in *Saccharum spontaneum* (3.40 ± 0.52) followed by *Saccharum bengalense* (0.30 ± 0.002) and there was no larval stage found in the nesting material of *Rosa* spp. (0.00 ± 0.00).

4.1.8 Number of pupa

Nests were fully exposed by splitting the stem with the help of sharp knife. Following the splitting, number of pupa were recorded manually. Further persual of experimental findings revealed the maximum average number of pupa was observed

Table 4.1: Nest architecture of *Ceratina viridissima*

Nest material	Length of nest (mm)	Width of nest entrance (mm)	Length of chamber (mm)	Breadth of chamber (mm)	Number of chamber	Number of adult bees	Number of larva	Number of pupa
***Rosa* spp.**	5.79 ± 1.38 [a]	2.58 ±0.18[a]	2.01 ± 0.34[a]	0.36 ±0.24[a]	0.20 ± 0.01[a]	1.30 ±0.12[a]	0.00 ±0.00[a]	0.00 ±0.00[a]
***Saccharum sponateum* (Sarkanda)**	20.77±0.78[c]	2.60 ±0.07[a]	16.82 ±1.00[b]	3.06 ± 0.22[b]	5.80 ±0.74[b]	2.80 ±0.48[b]	3.40 ± 0.52[b]	1.80 ±0.02[b]
***Saccharum bengansle* (Kae)**	14.38 ±0.73[b]	2.62 ±0.07[a]	8.17 ± 0.86[a]	2.12 ± 0.50[a]	1.40 ±0.03[a]	1.10 ±0.01[a]	0.30±0.002[a]	0.20 ±0.001[a]

Mean± SE in the same column followed by different letters are significantly different (Anova , P <0.05),SE=Standard error

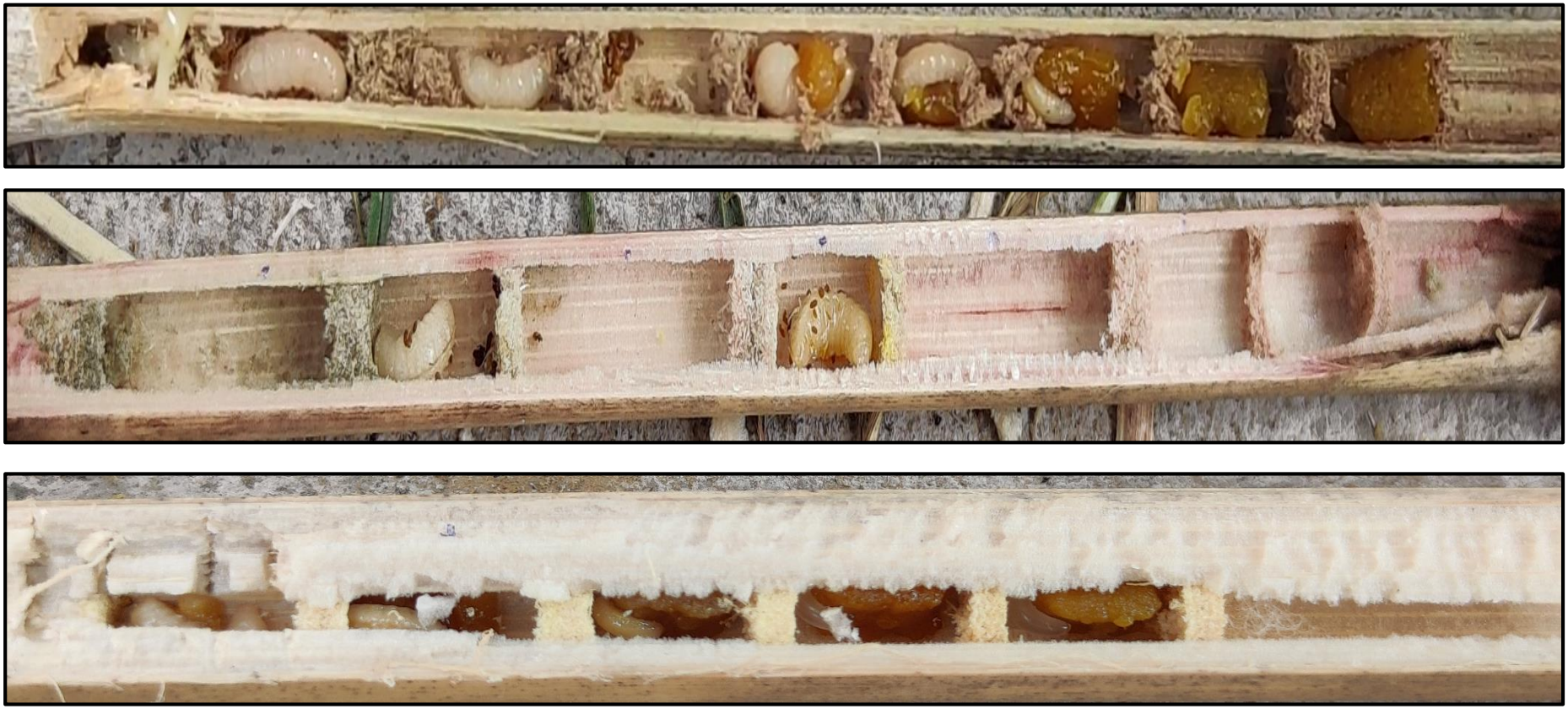


Plate 4.1 : Nest architecture of *Ceratina viridissima* in pithy stalks of *Saccharum spontaneum* (sarkanda).

in *Saccharum spontaneum* (1.80 ± 0.02) followed by *Saccharum bengalense* (0.20 ± 0.001) and there was also no pupal stage found in the nesting material of *Rosa* spp. (0.00 ± 0.00).

4.2 Nest preference

Experimental results as depicted in (Table 4.1 and Figure 4.1) indicated that most preferred nesting material by *Ceratina viridissima* was *Saccharum spontaneum* (Sarkanda) followed by *Saccharum bengalense* (Kae) and *Rosa* spp., based on observations recorded for various nesting parameters viz., average number of chambers, number of adult bees, number of larva and number of pupa.

4.3 Foraging Behavior of *Ceratina viridissima* on *Ocimum sanctum* and *Trifolium alexandrinum*

Ceratina viridissima forages on number of agricultural crops for carrying pollen load with them to the nest. It helps in pollination of various crops and enhances the productivity of the crops. In the persent study,we recorded the foraging behavior of the *Ceratina viridissima* on two specified crops one was *Ocimum sanctum* and other one was *Trifolium alexandrinum.*

4.3.1 Foraging behavior of *Ceratina viridissima* on *Ocimum sanctum*

Based on the observations recorded on various weather parameters viz., sunshine, temperature, relative humidity and evaporation taken in the month of March, 2021 to delineate the effect of above mentioned weather parameters on foraging behavior of *Ceratina viridissima* is depicted in (Table 4.2). Experimental results are comprehensively described under following subheadings:

4.3.1.1 Time spent on flower

Maximum time spent on flower was recorded (98 s) at the maximum and minimum temperature of 31.5℃ and 13.4℃ with relative humidity 83 per cent (morning) and 41 per cent (evening), sunshine of 8.9 hours and evaporation of 2mm.Similarly minimum time spent on flower was recorded to be (29 s) at the maximum and minimum temperature of 20.8^{o}C and 15.4^{o}C with morning and evening relative humidity of 74% and 94%, sunshine of 1.1 hours and evaporation of 0.8mm respectively. Experimental results further revealed that average time spent on flower by *Ceratina viridissima* was recorded to be (55.26 ± 20.77 s).

4.3.1.2 Number of flowers visited per minute

Maximum number of flowers visited per minute by *Ceratina viridissima* was recorded (20) at the maximum and minimum temperature of 31.5℃ and 13.4℃ with relative humidity 83 per cent (morning) and 41 per cent (evening), sunshine of 8.9 hours and evaporation of 2mm. Similarly minimum number of flowers visited per minute was recorded (1) at maximum and minimum temperature of (20.5℃, 21.2℃, 26.6℃, 20.8℃ & 26.8℃) and (10.4ºC, 12.4℃, 14.6℃ & 15.4℃) with morning and evening relative humidity of (74%, 77% & 88%) and (36%, 51%, 81%, 62% & 94%), sunshine of (1.1hrs, 1.2hrs, 1.3hrs and 2.9hrs) and evaporation of (0.8mm, 1.46mm and 1.6mm) respectively. Experimental findings also revealed that average number of flowers visited per minute by *Ceratina viridissima* was recorded to be (6.53 ± 1.29).

4.3.2 Foraging behavior of *Ceratina viridissima* on *Trifolium alexandrinum*

Based on the observations recorded on various weather parameters viz., sunshine, temperature, relative humidity and evaporation taken in the month of March, 2021 to delineate the effect of above mentioned weather parameters on foraging behavior of *Ceratina viridissima* is depicted in (Table 4.3). Experimental results are comprehensively described under following subheadings:

4.3.2.1 Time spent on flower

Maximum time spent by *Ceratina viridissima* on flowers of *Trifolium alexandrinum* was recorded to be (30s) at maximum and minimum temperatures 29.0℃ and 10.6℃ with morning and evening relative humidity of 82% and 41%, sunshine of 7.8 hours and evaporation of 1.86mm.Similarly minimum time spent on flower was recorded (1.45s) at maximum and minimum temperature of 22.8ºC and 14.4ºC with morning and evening relative humidity 84% and 64%, sunshine of 6.9 hours and evaporation of 1.46mm respectively. Further perusal of experimental findings revealed that average time spent by *Ceratina viridissima* on flowers of *Trifolium alexandrinum* was recorded (13.53 ± 8.64 s).

4.3.2.2 Number of flowers visited per minute

Maximum number of flowers visited per minute was recorded (24) at maximum and minimum temperature of 22.8ºC and 10.8ºC with morning and evening relative humidity of 74% and 61%, sunshine of 3.1 hours and evaporation of 3.72mm respectively. Similarly minimum number of flowers visited was recorded (2 flowers

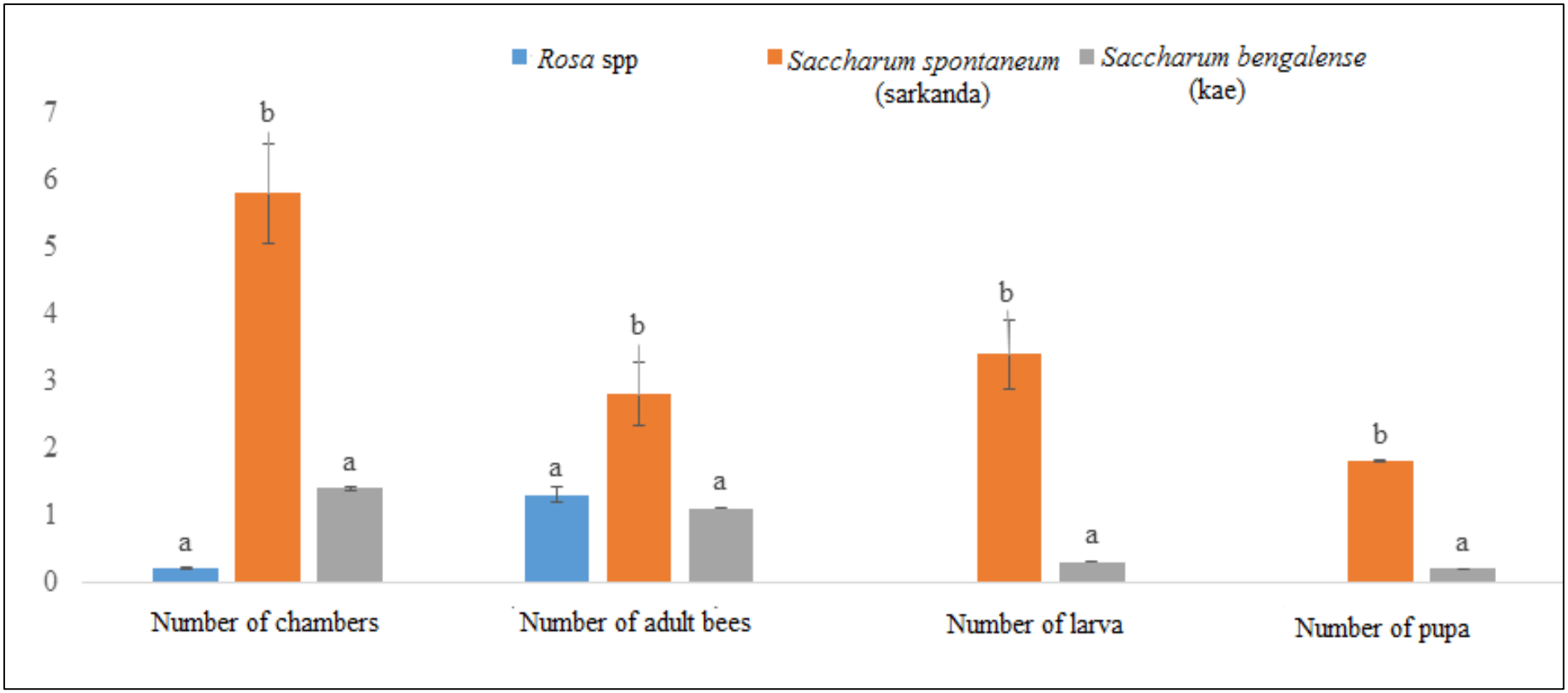


Figure 4.1 : Nesting preference of *Ceratina viridissima*

Table 4.2 : Foraging behavior of *Ceratina viridissima* on *Ocimum sanctum*

Standard days	Time spent on flower (s)	Number of flowers visited per min.	Temperature (^{0}C)		Relative Humidity (%)		Sunshine (hrs)	Evaporation (mm)
			Max.	Min.	Morning	Evening		
01/03/2021	34	2	20.6	10.2	94	53	2.9	3.76
02/03/2021	46	2	22.8	10.8	85	50	3	3.66
03/03/2021	45	3	21.7	11.8	90	40	3	3.55
04/03/2021	33	1	20.5	12.4	77	36	2.9	3.66
05/03/2021	47	2	22.8	10.8	74	61	3.1	3.72
06/03/2021	48	4	21.9	13.4	90	41	3.5	1.46
07/03/2021	49	2	22.8	12.8	87	59	3.3	1.87
08/03/2021	47	3	22.9	13.4	90	41	3.5	1.86
09/03/2021	58	7	30.4	12.4	79	45	5.7	1.46
10/03/2021	78	11	30.5	14.2	78	32	7.3	1.93
11/03/2021	39	5	27.8	13.5	71	40	4.8	1.46
12/03/2021	36	1	21.2	14.6	88	81	1.1	0.8
13/03/2021	34	1	26.6	10.4	74	51	1.2	1.66
14/03/2021	45	3	26.5	11.8	80	54	3.3	1.93
15/03/2021	48	3	27.4	10.8	95	54	3.1	3.66
16/03/2021	33	2	28.8	13.4	86	51	2.9	1.66
17/03/2021	45	3	29	12.8	91	41	3	1.66
18/03/2021	49	4	30	12.4	89	51	3.5	1.86
19/03/2021	57	9	30.4	12.6	77	37	6.1	1.93
20/03/2021	80	14	30.6	11.8	81	35	7.7	1.86
21/03/2021	60	10	22.8	14.4	84	64	6.9	1.46
22/03/2021	29	1	20.8	15.4	74	94	1.1	0.8
23/03/2021	36	1	26.8	15.4	74	62	1.3	1.46
24/03/2021	55	6	27	14	83	41	5.1	1.73
25/03/2021	95	17	27.6	10.2	90	42	8.3	1.73
26/03/2021	89	15	29	10.6	82	41	7.8	1.86
27/03/2021	97	19	30.5	13.4	79	51	8.6	1.86
28/03/2021	79	13	31.4	16	87	59	7.3	1.86
29/03/2021	69	12	32.5	20.4	60	55	7.1	2
30/03/2021	98	20	31.5	13.4	83	41	8.9	2
Mean	**55.26**	**6.53**	**26.5**	**12.98**	**82.4**	**50.1**	**4.57**	**2.07**
S.dv	**10.77**	**0.29**	**3.9**	**2.13**	**7.79**	**13.49**	**2.44**	**0.86**

Table 4.3 : Foraging behavior of *Ceratina viridissima* on *Trifolium alexandrinum*

Standard days	Time spent on flower (s)	Number of flowers visited per min.	Temperature (^{0}C)		Relative Humidity (%)		Sunshine (hrs)	Evaporation (mm)
			Max.	Min.	Morning	Evening		
01/03/2021	10	12	20.6	10.2	94	53	2.9	3.76
02/03/2021	20	14	22.8	10.8	85	50	3.00	3.66
03/03/2021	7.8	16	21.7	11.8	90	40	3.00	3.55
04/03/2021	9.2	8	20.5	12.4	77	36	2.9	3.66
05/03/2021	5.6	24	22.8	10.8	74	61	3.1	3.72
06/03/2021	6.9	21	21.9	13.4	90	41	3.5	1.46
07/03/2021	3.6	20	22.8	12.8	87	59	3.3	1.87
08/03/2021	7.6	19	22.9	13.4	90	41	3.5	1.86
09/03/2021	19	5	30.4	12.4	79	45	5.7	1.46
10/03/2021	17	3	30.5	14.2	78	32	7.3	1.93
11/03/2021	7.3	13	27.8	13.5	71	40	4.8	1.46
12/03/2021	6.3	9	21.2	14.6	88	81	1.1	0.8
13/03/2021	25	4	26.6	10.4	74	51	1.2	1.66
14/03/2021	6.9	13	26.5	11.8	80	54	3.3	1.93
15/03/2021	7	17	27.4	10.8	95	54	3.1	3.66
16/03/2021	2.5	18	28.8	13.4	86	51	2.9	1.66
17/03/2021	1.5	15	29	12.8	91	41	3.00	1.66
18/03/2021	15	2	30	12.4	89	51	3.5	1.86
19/03/2021	18	3	30.4	12.6	77	37	6.1	1.93
20/03/2021	28	7	30.6	11.8	81	35	7.7	1.86
21/03/2021	1.45	10	22.8	14.4	84	64	6.9	1.46
22/03/2021	10	6	20.8	15.4	74	94	1.1	0.8
23/03/2021	14	3	26.8	15.4	74	62	1.3	1.46
24/03/2021	20	2	27	14	83	41	5.1	1.73
25/03/2021	24	4	27.6	10.2	90	42	8.3	1.73
26/03/2021	30	3	29	10.6	82	41	7.8	1.86
27/03/2021	28	2	30.5	13.4	79	51	8.6	1.86
28/03/2021	10.5	9	31.4	16	87	59	7.3	1.86
29/03/2021	26	5	32.5	20.4	60	55	7.1	2.00
30/03/2021	17.8	6	31.5	13.4	83	41	8.9	2.00
Mean	**13.53**	**9.76**	**26.5**	**12.98**	**82.4**	**50.1**	**4.57**	**2.07**
S.dv	**0.64**	**0.6**	**3.9**	**2.13**	**7.79**	**13.49**	**2.44**	**0.86**

per minute) at maximum temperature of (27.0℃, 30.0℃ & 30.5℃) and minimum temperature of (14.0℃, 12.4℃ & 13.4℃) with morning and evening relative humidity of (83%, 89% &79%) and (51%,41% & 51%), sunshine of (3.5, 5.1 & 8.6 hours) and evaporation of (1.73mm & 1.86mm) respectively. Experimental findings also revealed that average number of flowers visited per minute was recorded (9.76 ± 6.60).

4.3.3 Foraging Activity Period of *Ceratina viridissima*

Present study revealed that *Ceratina viridissima* started its foraging activity in the morning hours and stopped its activity in the evening hours. The data presented in the (Table 4.4) revealed that it started its foraging activity at 9:00 am to 10:00 am in the morning hours when there was enough sunshine. The time of cessation of its foraging activity was 5:00 pm to 5:40 pm in the evening hours.

4.4 Effect of Weather Parameters on Foraging Behavior of *Ceratina viridissima* on Selected Crops

4.4.1 *Ocimum sanctum*

Data presented in the (Table 4.5) revealed that there was positive significant relation between time spent on flowers by *Ceratina viridissima* with maximum temperature (r = 0.628) and sunshine hours (r = 0.938), while rest of the weather parameters viz., relative humidity, minimum temperature and evaporation were observed to have non-significant association with time spent on flower. Based on the R^2 value (Figure 4.2 and Figure 4.3), sunshine hours had strong association with time spent on flowers (85%), while mean temperature and time spent on flowers was observed to weak association with each other (23%). Data presented in the (Table 4.6) revealed positive and significant relation of number of flowers visited by *Ceratina viridissima* with maximum temperature (r = 0.654) and sunshine hours (r = 0.961) respectively. However, rest of the weather parameters viz., relative humidity, minimum temperature and evaporation were observed to have non-significant association with number of flowers visited per minute. Above mentioned correlation results were further supported by R^2 values (Figure 4.2 and Figure 4.3) indicating strong association (81%) between the sunshine hours and number of flowers visited per minute while as weak association (14%) between the mean temperature and number of flowers visited per minute.

4.4.2 *Trifolium alexandrinum*

Data presented in the (Table 4.7) revealed that there was positive significant relation between the time spent on flower by *Ceratina viridissima* with maximum temperature(r = 0.527) and sunshine hours(r = 0.547) while rest of the weather parameters viz., relative humidity, minimum temperature and evaporation were observed to have non-significant association with time spent on flower. Based on the R^2 value (Figure 4.4 and Figure 4.5), sunshine hours was observed to have strong association (72%) with time spent on flower by *Ceratina viridissima*, while as weak association (21%) was observed between mean temperature and time spent on flower. Data presented in the (Table 4.8) indicated that presence of positive significant relation between the number of flowers visited by *Ceratina viridissima* with maximum temperature(r = 0.507) and sunshine hours (r = 0.417) while as rest of the weather parameters viz., minimum temperature, morning relative humidity, evening relative humidity and evaporation were observed to have non-significant association with flowers visited per minute by *Ceratina viridissima*. Above mentioned correlation results were further supported by R^2 value (Figure 4.4 and Figure 4.5) indicating strong association of sunshine hours with flowers visited per minute while as weak association was reported between mean temperature and flowers visited per minute.

4.5. Morphometric study of *Ceratina viridissima*

Morphometric study of *Ceratina viridissima* was carried in laboratory conditions under Leica microscope by using LASV5 software. In present study twenty specimen of *Ceratina viridissima* were used for the morphometric estimation and data is depicted in (Table 4.9) and results are briefly explained below:

4.5.1 Length of body (mm)

Average length of body was recorded to be (13.49 ± 0.58 mm).

4.5.2 Length of Head (mm)

Average length of head was recorded to be (3.22 ± 0.06 mm).

4.5.3 Breadth of head (mm)

Average breadth of the head was observed to be (3.29 ± 0.18mm).

4.5.4 Length of antenna (mm)

Average length of antenna was observed to be (1.09 ± 0.01 mm).

Table 4.4 : Initiation and Cessation of Foraging activity of *Ceratina viridissima*

Nest no.	Time of activity initiation from the nest	Time of activity cessation to the nest
N1	9.09 am	10:26 am
N2	9:28 am	10.00 am
N3	9.35 am	10:23 am
N4	9:37 am	9:39 am
N5	9:50 am	9:56 am
N6	11:00 am	11:05 am
N7	11:35 am	11:37 am
N8	12:10 pm	12:20 pm
N9	11:30 am	11:50 am
N10	12:17 pm	1:00 pm
N11	2:35 pm	2:45 pm
N12	3:00 pm	3:05 pm
N13	4:50 pm	5:20 pm
N14	5:18 pm	5:30 pm
N15	5:22 pm	5:40 pm

N: Nest

Table 4.5: Correlation coefficient between weather parameters and time spent by *Ceratina viridissima* on *Ocimum sanctum*

	Temperature (°C)		Relative Humidity (%)		Sunshine hours (hrs)	Evaporation (mm)
	Maximum	Minimum	Morning	Evening		
Time spent by *Ceratina viridissima* on flower	0.628**	0.052NS	-0.025NS	-0.361NS	0.938**	-0.127NS

**Significant at the 0.01 level

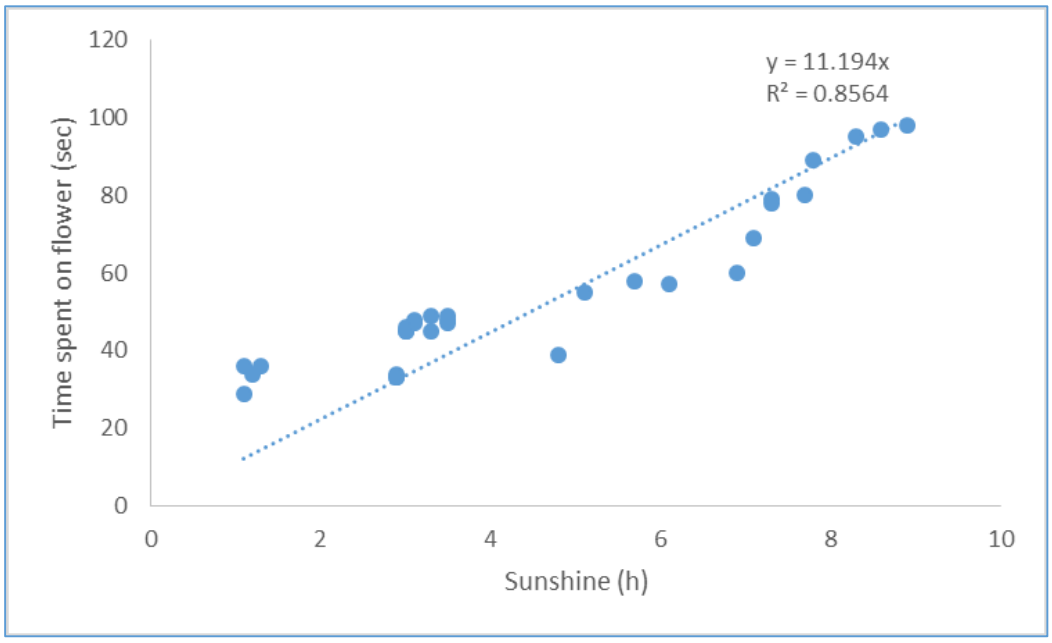
*Significant at the 0.05 level

Table 4.6: Correlation coefficient between weather parameters and number of flowers visited per minute by *Ceratina viridissima* on *Ocimum sanctum*

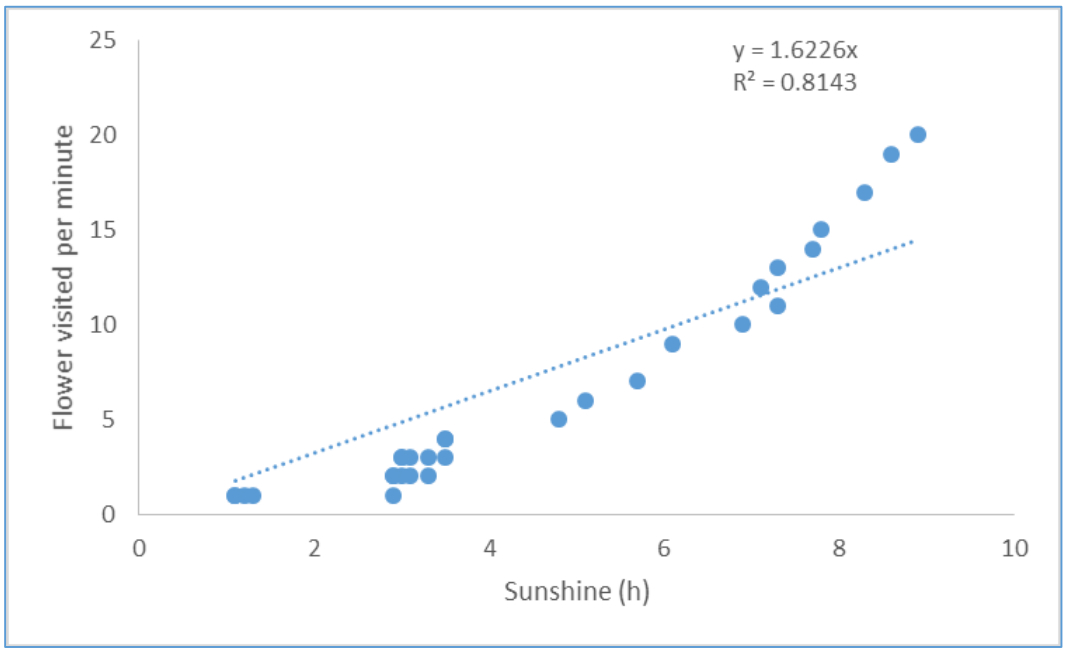
	Temperature (°C)		Relative Humidity (%)		Sunshine hours (hrs)	Evaporation (mm)
	Maximum	Minimum	Morning	Evening		
Number of flowers visited per minute by *Ceratina viridissima*	0.654**	0.135NS	-0.115NS	-0.332NS	0.961**	-0.197NS

**Significant at the 0.01 level

*Significant at the 0.05 level

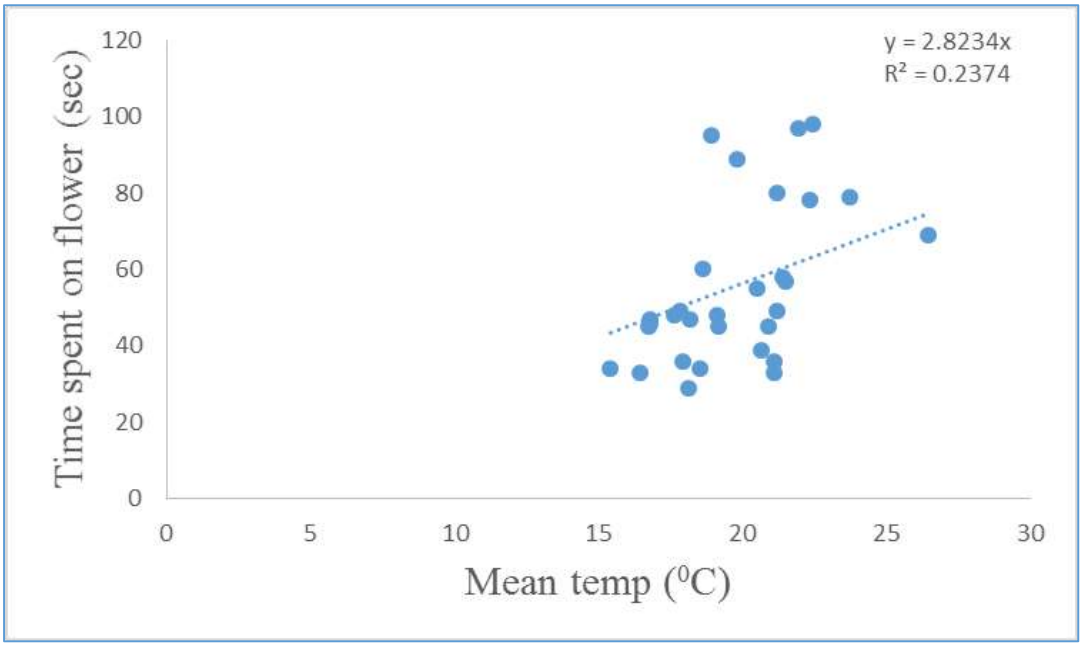


(a) Association of time spent on flower by *Ceratina viridissima* with sunshine.

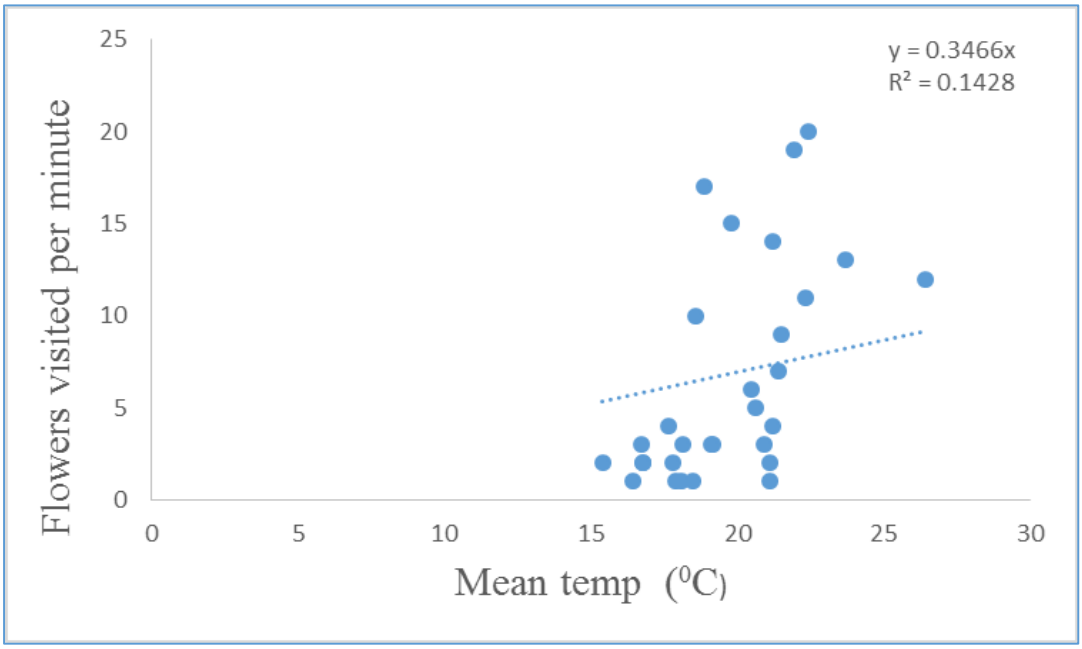


(b) Association of number of flowers visited per minute by *Ceratina viridissima* with sunshine.

Figure 4.2 : Effect of sunshine on foraging behavior of *Ceratina viridissima* on *Ocimum sanctum*



(a) Association of time spent on flower by *Ceratina viridissima* with temperature



(b) Association of number of flowers visited per minute by *Ceratina viridissima* with temperature

Figure 4.3 : Effect of temperature on foraging behavior of *Ceratina viridissima* on *Ocimum sanctum*

Table 4.7 : Correlation coefficient between weather parameters and time spent by *Ceratina viridissima* on *Trifolium alexandrinum*

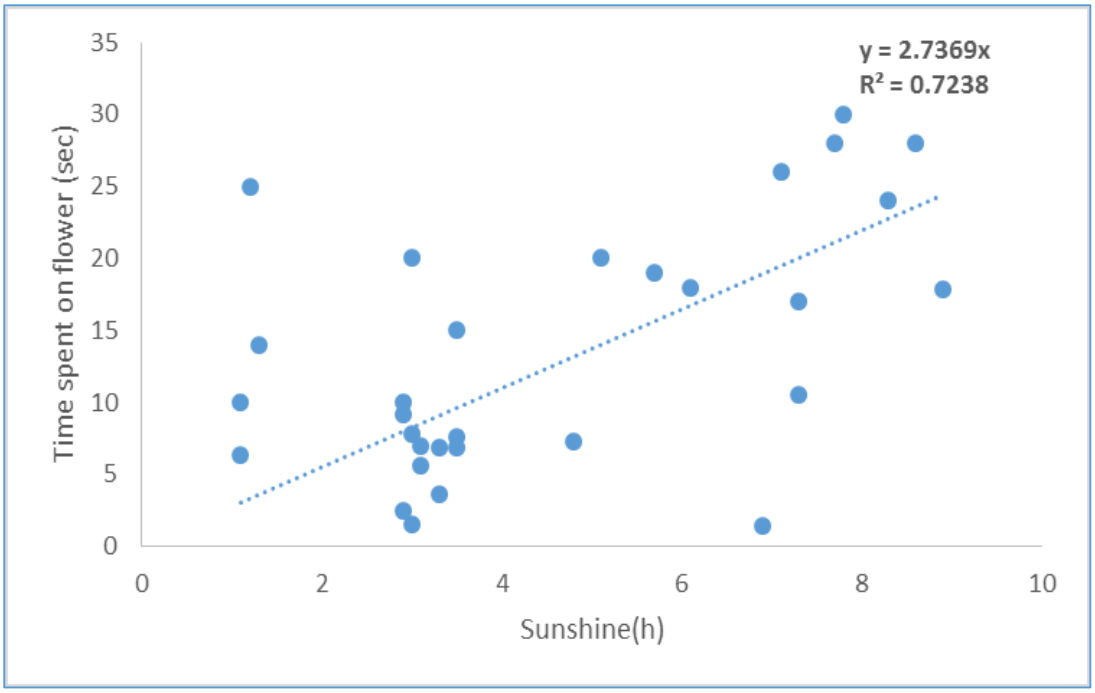
	Temperature (°C)		Relative Humidity (%)		Sunshine hours (hrs)	Evaporation (mm)
Time spent by *Ceratina viridissima* on flower	**Maximum**	**Minimum**	**Morning**	**Evening**		
	0.527^{**}	-0.037^{NS}	-0.368^{NS}	-0.302^{NS}	0.547^{**}	-0.081^{NS}

**Significant at the 0.01 level
*Significant at the 0.05 level

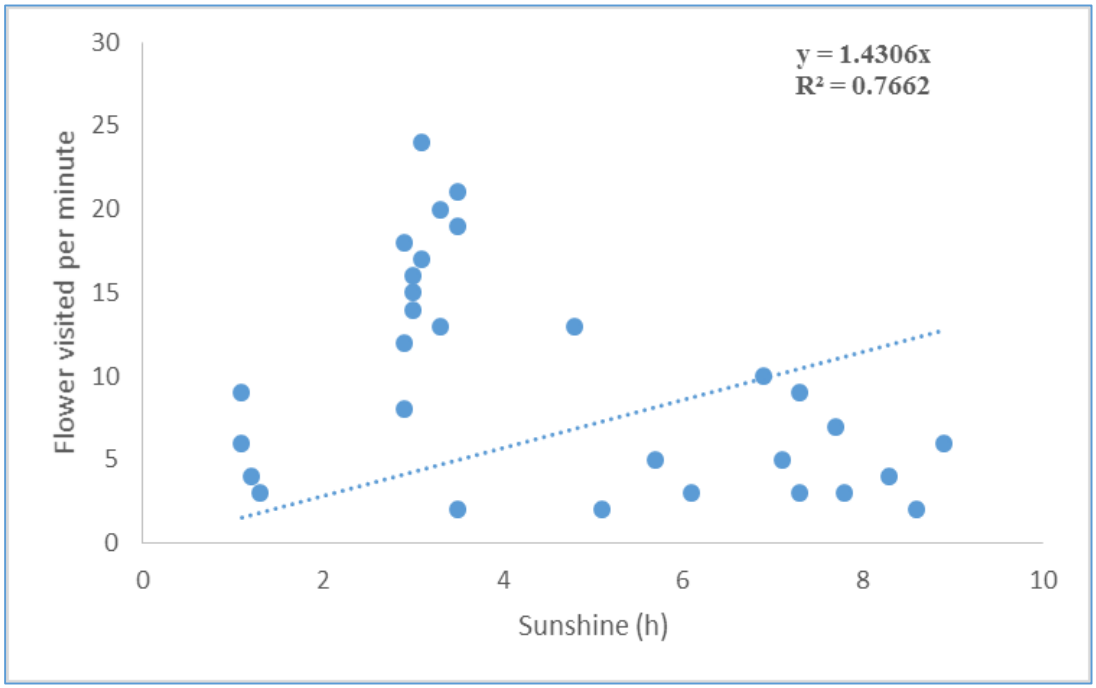
Table 4.8 : Correlation coefficient between weather parameters and number of flowers visited per minute by *Ceratina viridissima* on *Trifolium alexandrinum*

	Temperature (°C)		Relative Humidity (%)		Sunshine hours (hrs)	Evaporation (mm)
Number of flowers visited per minute by *Ceratina viridissima*	**Maximum**	**Minimum**	**Morning**	**Evening**		
	0.507^{**}	-0.212^{NS}	0.367^{NS}	0.066^{NS}	0.417^{*}	0.367^{NS}

**Significant at the 0.01 level
*Significant at the 0.05 level

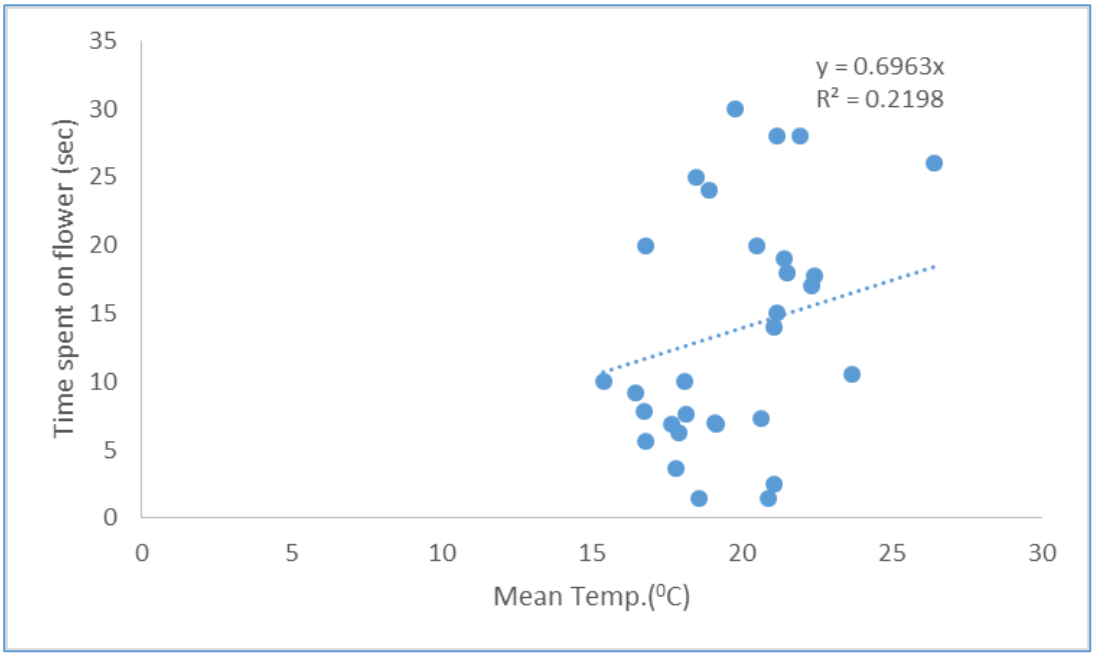


(a) Association of time spent on flower by *Ceratina viridissima* with sunshine.

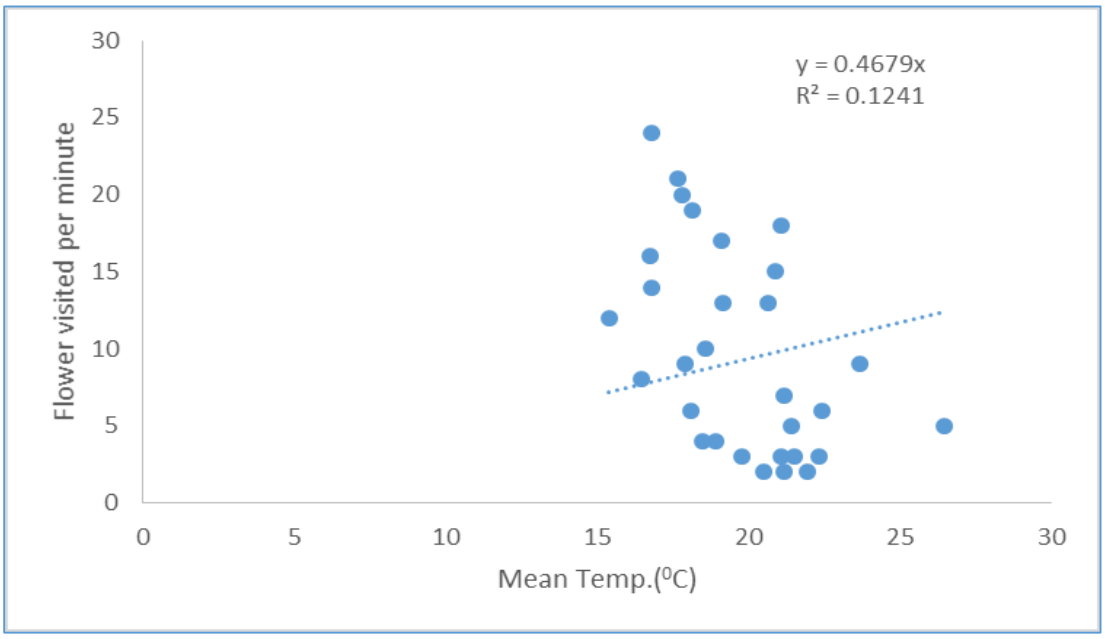


(b) Association of number of flowers visited per minute by *Ceratina viridissima* with sunshine.

Figure 4.4: Effect of sunshine on foraging behavior of *Ceratina viridissima* on *Trifolium alexandrinum.*



(a) Association of time spent on flower by *Ceratina viridissima* with temperature.



(b) Association of number of flowers visited per minute by *Ceratina viridissima* with temperature.

Figure 4.5: Effect of temperature on foraging behavior of *Ceratina viridissima* on *Trifolium alexandrinum*.

Table 4.9 : Morphometric studies of *Ceratina viridissima*

S.No	Morphometric Parameters	Size (mm)
1	Length of body	13.49 ±0.58
2	Length of head	3.22 ±0.06
3	Breadth of head	3.29 ±0.18
4	Length of antennae	1.09 ±0.01
5	Length of forewing	7.61 ±0.03
6	Breadth of forewing	3.08 ±0.02
7	Length of hindwing	4.95 ±0.03
8	Breadth of hindwing	0.81 ±0.04
9	Length of foreleg	4.20 ±0.01
10	Length of middle leg	5.31 ±0.03
11	Length of hindleg	6.23 ±0.02
12	Length of proboscis	1.43±0.01

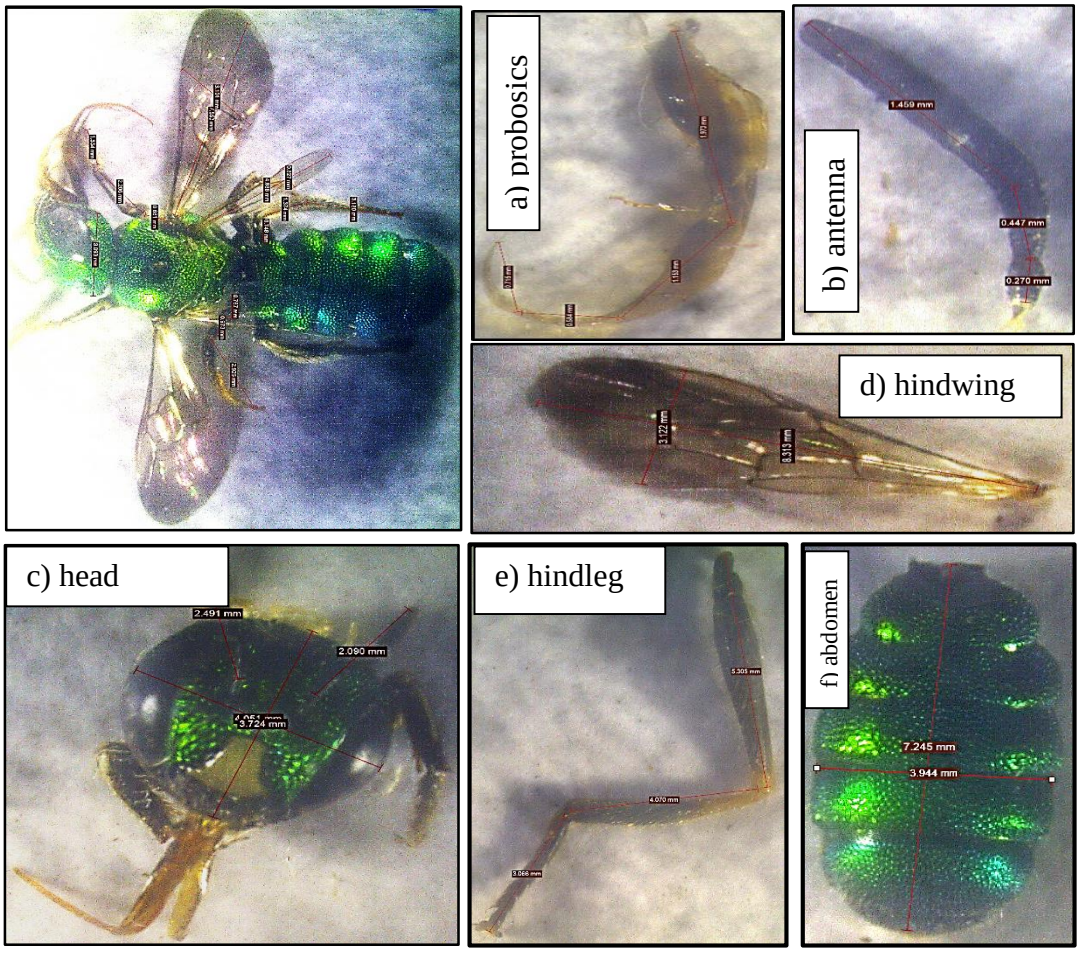


Plate No. 4.2 : Microscopic view of *Ceratina virridissima*

4.5.5 Length of forewing (mm)

Average length of forewing was recorded to be (7.61 ± 0.03 mm)

4.5.6 Breadth of forewing (mm)

Average breadth of forewing was recorded to be (3.08 ± 0.02 mm)

4.5.7 Length of hindwing (mm)

Average length of hindwing was observed to be (4.95 ± 0.03 mm)

4.5.8 Breadth of hindwing (mm)

Average breadth of hindwing was observed to be (0.81 ± 0.04 mm)

4.5.9 Length of foreleg (mm)

Average length of forelegs was recorded to be (4.20 ± 0.01 mm).

4.5.10 Length of middle leg (mm)

The average length of middle legs was (5.31 ± 0.03 mm) .

4.5.11 Length of hindleg (mm)

The average length of hindlegs was (6.23 ± 0.02 mm).

4.5.12 Length of proboscis (mm)

The average length of probosics was (1.43 ± 0.01 mm) .

CHAPTER 5

DISCUSSION

The present investigation was done to study the nest architecture,foraging behavior and morphometric characters of *Ceratina viridissima*. The results obtainted have been discussed below with the help of relevant literature and explaination wherever possible.

5.1 Nest architecture of *Ceratina viridissima*

Analysis of variance revealed the presence of significant variation for the various nesting parameters viz., length of nest, width of nest entrance, length and breadth of chambers, number of chambers, number of adult bee, number of larva and number of pupa. Ali *et.al.,* 2016 and Kaliaperumal 2019 are in agreement with the findings of present study. The present study also indicated absence of immature stages and chamber formation in *Rosa* spp. due to its hard stalk as compared to *Saccharum spontaneum.* The present study also confirmed that the *Ceratina viridissima* preferred *Saccharum spontaneum* for nesting in comparison to other nesting material viz. *Rosa* spp. and *Saccharum bengalense*. However, the observations in the present study differed from the earlier studies (Malaipan and Orostrirat, 1992., Rehan *et al*., 2009., Rehan and Richard, 2009., Vickruck, 2010., Hongjamrassilpl and Warrit, 2014., Rehan *et al*., 2015., Yogi and Khan, 2016., Rehan *et al*., 2009., Udayakumar and Shivalingaswamy, 2019., Sneha Latha *et al*., 2020 and Mikal *et al*., 2021). The variation in results was due to the utilization of varied nesting materials, species of Ceratina and environmental conditions.

5.2 Foraging behavior of *Ceratina viridissima*

Small carpenter bee plays a significant role in improving the productivity of crops. The enormous population of these wild bees helps in pollination during flowering time. The foraging speed and foraging rate of the small carpenter bees increases the yield and productivity of crops.

5.2.1 Foraging behavior of *Ceratina viridissima* on *Ocimum sanctum*

Present study revealed the average time spent on flower was recorded (55.26 ± 10.77 s) while as average number of flower visited per minute was (6.53 ± 0.29). Maximum time spent on flower was observed (98s) and minimum time spent on

flower was (29 s). Study also revealed the maximum number of flowers visited per minute was (20) and minimum number of flowers visited per minute was (1) irrespective of different hours of the day in the month of march. Similar results were reported by Raju,2008 who stated that Pithitis visited more number of flowers per minute if the flower occurs in clusters (*Ocimum* spp. and *Trifolium alexandrinum*) and takes more time per flower for forage collection and visit a small number of flower if flowers occurs singly.

5.2.2 Foraging behavior of *Ceratina viridissima* on *Trifolium alexandrinum*

Investigation of foraging behavior of *Ceratina viridissima* on *Trifolium alexandrinum* confirmed the average time spent on flower was recorded (13.53 ± 0.64 s) and the average number of flowers visited per minute was recorded (9.76 ± 0.60).The maximum time spent on flower was (30s) and minimum time spent on flower was (1.45s). Findings of present study also revealed the maximum number of flower visited per minute was (24) and minimum number of flower visited was (2) irrespective of different hours of the day in the month of March. Raju, 2008 in a similar study reported that Pithitis visited more number of flowers per minute if the flower occurs in clusters (*Ocimum* spp. and *Trifolium alexandrinum*) and takes more time per flower for forage collection and visit a small number of flower if flowers occurs singly. The present studies are in consonance with findings of Batra, 1977 who reported *Pithitis smaragdula* as most efficient and effective pollinator of Medicago in United States. This bee has also been managed successfully in India for pollination of crops especially leguminous crops and *Medicago sativa* (Atwal, 1970 and Sandhu *et al*., 1976).

5.2.3 Foraging activity period of *Ceratina viridissima*

Findings of present study confirmed that the *Ceratina viridissima* starts its foraging activity in morning hours (9:00 a.m) and made many trips for carrying pollen load from the crop in different hours of the day. Study also confirmed that the *Ceratina viridissima* initiates its foraging activity at late hours of the morning. The time of cessation of foraging activity was evening hours (5:40 pm). Similar finding were reported by Ali *et.al.,* 2016 who concluded that *Ceratina smaragdula* is polylectic and visited diverse floral resources including alfalfa, oil seed rape, vegetable crops viz., okra, sponge gourd and pumpkin. The bees started foraging

activity in the early morning (6:54 a.m. ± 23 min) and spent an average (±SD) 25.4 ± 7.1 s on each flower, ending their daily foraging bouts in the late afternoon around 4:47 p.m. ± 35 minutes.

5.3 Effect of weather parameters on the foraging behavior of *Ceratina viridissima* on selected crops

Foraging behavior of *Ceratina viridissima* on *Ocimum sanctum* and *Trifolium alexandrinum* was observed to vary as per prevailing weather conditions. Experimental results revealed positive and significant association of time spent on flower with weather parameters viz., maximum temperature and sunshine hours. Study also confirmed that foraging activity increases with increase in maximum temperature and daily sunshine hours.The findings of this study also confirmed presence of positive and significant association of flowers visited per minute with weather parameters viz.,maximum temperature and sunshine hours. The result obtained from the present study were supported by Sharma and Abrol, 2017,who stated that abundance of *Amegilla zonata* on blooming *Ocimum kilimandrischium* in relation to abiotic variables revealed that temperature (maximum and minimum) and sunshine had a positive and significant effect on *Amegilla zonata* foraging while relative humidity (maximum and minimum), rainfall and wind speed had a negative impact.

5.4 Morphometric study of *Ceratina viridissima*

Morphometrics is the quantitative analysis of form, which includes size and shape. Morphometric analyses on organisms are commonly performed to assess the impact of mutations on shape, developmental changes in form, covariances between ecological factors and shape, and to estimate quantitative-genetic parameters of shape. In present study morphometric characterization was carried using Leica microscope. Findings of the present study revealed that length of body was recorded to be (13.49 ± 0.58), length of head (3.22 ± 0.06), length of antennae (1.09 ± 0.09), length of forewing (7.61 ± 0.03), length of hind wing (4.95 ± 0.03), length of foreleg (4.20 ± 0.01), length of middle leg (5.31 ± 0.03), length of hind length (6.23 ± 0.02) and length of proboscis (1.43 ± 0.01) while as breadth of head (3.29 ± 0.18), breadth of forewing (3.08) and breadth of hindwing (0.81 ± 0.04), respectively. The results

obtained from present morphometric study were not reported by earlier researchers on this particular specie (*Ceratina viridissima*).

In a similar study, Parmar, 2019 described the morphometric parameters of immature stages *Ceratina smaragdula from* Rajasthan, India. The average length of 3rd instar larval body was slender with rather distinct inter-segmental lines with average length of 8.2 mm. The total length of pupa was 12.1 mm with median length (1.15mm) and width (2.1mm) of head. Oliveria *et al.*, 2020 in another study described a new species of small carpenter, genus Ceratina (Ceratinula) Moure, by using the type specimen *C.manni* and provided an identification key for the Ceratina (Ceratinula) species recorded for Brazil in Moure's catalogue of Neotropical bees. Specimens were studied and photographed using a Leica M165C stereomicroscope coupled to a Leica DFC295 digital camera, containing the program LEICA application suite 4.1. Interactive Measurements, Montage.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The present study entitled **"Nest architecture and foraging behavior of *Ceratina viridissima* (Dalla Torre)''**was carried out keeping in view to study the nest architecture of *Ceratina viridissima,* to study the foraging behavior on selected crop and morphometric study.

In the present study the nesting material were selected from different planting material viz., *Rosa* spp., *Saccharum spontaneum* (Sarkanda) and *Saccharum bengalense* (kae) and observations were recorded on various nesting parameters and were subjected to statistical analysis using software (SPSS.16). Investigation of foraging behavior of *Ceratina viridissima* on *Ocimum sanctum* and *Trifolium alexandrinum* revealed that time spent on flower (s) and number of flower visited per minute were having significant and positive relation with maximum temperature and daily sunshine hours. Morphometric study was carried using Leica microscope for estimates of dimensions of different body parts of *Ceratina viridissima*.The results pertaining to the objectives of present study are summarized as under:

- Present study revealed that the nesting material *Saccharum spontaneum* (Sarkanda) was preferred most by *Ceratina viridissima* for nesting purposes followed by *Saccharum bengalense* (Kae) and *Rosa* spp. The nesting parameters observed in *Saccharum spontaneum* was found to be differed significantly such as (Length of nest = 20.77 ± 0.78 mm), (Width of nest entrance = 2.60 ± 0.07mm), (Length of chamber = 16.82 ± 1.00mm), (Breadth of chamber = 3.06 ± 0.22mm), (Number of chambers = 5.80 ± 0.74), (Number of adult bees = 2.80 ± 0.48) (Number of larva =3.40 ± 0.52) and (Number of pupa = 1.80 ± 0.02).
- The foraging behavior of *Ceratina viridissima* was recorded in *Ocimum sanctum* and *Trifolium alexandrinum* having positive and significant association with maximum temperature and daily sunshine hours.
- The morphometric study was done under Leica microscope revealed the dimensions of body size such as (Length of body = 13.49 ± 0.58mm), (Length of head =3.22 ± 0.06mm), (Breadth of head = 3.29 ± 0.18), (Length of antenna = 1.09 ± 0.01mm), (Length of forewing = 7.61 ± 0.03mm), (Breadth of forewing = 3.08 ±

0.02mm), (Length of hindwing = 4.95 ± 0.03mm), (Breadth of hindwing = 0.81 ± 0.04mm), (Length of forelegs = 4.20 ± 0.01mm), (Length of middle legs = 5.31 ± 0.03mm), (Length of hindlegs = 6.23 ± 0.02mm) and (Length of proboscis = 1.43 ± 0.01mm) which would help in comparative study of different Ceratina species.

- The present study will help in conservation of *Ceratina viridissima* through provisioning of artificial nesting structure.
- Conservation of these bees provides valuable ecosystem service in terms of crop pollination.
- The establishment of nesting structures of small carpenter bee provide better alternatives for farmers to facilitate pollination of their crops.

VITA

Name of the Student	:	Shallu Choudhary
Father's Name	:	Bishan Dass Choudhary
Mother's Name	:	Shakti Devi
Nationality	:	Indian
Date of Birth	:	23-02-1995
Permanent Home Address	:	Village: Gurha Singhu, Tehsil: Marh, District: Jammu (181206)
E-mail	:	choudhary.shally1995@gmail.com

EDUCATIONAL QUALIFICATION

Bachelor's Degree	:	BSc. (Hons.) Agriculture
University and Year of Award	:	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, 2019
OGPA	:	7.99
Master's Degree	:	M.Sc. Agriculture (Entomology)
University and Year of Award	:	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, 2021
OGPA	:	8.31

CERTIFICATE-IV

Certified that all the necessary corrections as suggested by the external examiner and the Advisory Committee have been duly incorporated in the thesis entitled **"Nest Architecture and Foraging Behavior of *Ceratina viridissima* (Dalla Torre)"** submitted by **Ms. Shallu Choudhary**, Registration No. **J-19-M-630**.

Dr. Devinder Sharma
Major Advisor

Place: Jammu

Date: 28-12-2021

Head of the Division