FLIGHT RANGE, COLONY CHARACTERISTICS AND POLLINATION EFFICACY OF STINGLESS BEE, *Tetragonula travancorica* IN CHILLI (*Capsicum annuum L.*)

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"FLIGHT RANGE, COLONY CHARACTERISTICS AND POLLINATION EFFICACY OF STINGLESS BEE, *Tetragonula travancorica* IN CHILLI (*Capsicum annuum L.*)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associate ship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"FLIGHT RANGE, COLONY CHARACTERISTICS AND POLLINATION EFFICACY OF STINGLESS BEE, *Tetragonula travancorica* IN CHILLI (*Capsicum annuum L.*)"** is a record of research work done independently by Ms. Bindu G R under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to her.

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EXTERNAL EXAMINER

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LIST OF ABBREVIATIONS AND SYMBOLS USED

NHB	National Horticulture Board
CD (0.05)	Critical difference at 5 % level
MT	Metric tonnes
%	Percent
km	Kilo meter
et al.	Co-workers/ Co-authors
m	Meters
Fig.	Figure
g	Gram
h	Hour
ha	Hectare
mL	Millilitre
cm	Centi meter
L	Litres
cm^2	Centimetre square
cm^3	Cubic centimeter
±	Plus or minus
mm	Millimetre
g	Gram
π	Pi or 3.14
WASP	First web Agricultural Statistics software

UTOB	Utrecht University- Tobago Hive
KAU	Kerala Agricultural university
°C	Degree Celsius
i.e.	That is
spp.	Species (pleural)
viz.,	Namely

Introduction

1. INTRODUCTION

Stingless bees are group of small to medium sized bees belonging to sub family Meliponinae of the family Apidae, found in tropical and subtropical parts of the world with vestigial sting. Unlike other eusocial bees, stingless bees do not have stingers, but generally defend themselves by biting with their strong mandibles. Stingless bees are active throughout the year, less active in cold conditions. It is also called as dammer bees.

Stingless bees are eusocial bees that live in colonies comprising of a queen, drone and many workers. The strength of the colony mainly depends on the number of workers, queen lead the entire colony and drones mate with the queen. In meliponaries, external nesting characters like nest architecture and internal nesting characters such as brood area and its dimensions, total number of food pots, volume, height and diameter of honey and pollen pots were considered for selection of productive colonies in commercial meliponiculture.

The species *T. travancorica* (Shanas and Faseeh) is often confused with T. iridipennis (Smith, 1854) which is restricted to Sri Lanka. *T. travancorica* distribution is mainly confined to peninsular India and easy to manage and widely multiplied as well as traded by the beekeepers of southern India.

Temperature is one of the abiotic factors which directly affects the metabolism of bees and influence the development of brood and adults. Air temperature largely affects the bee body and the ambient temperature of the nest, which in turn reduces the activity of bees (Naas 1989; Silva 2000; Vollet 2011). Thermoregulation is a process shown by the bees to prevent effect of high temperature on development of brood. It is necessary for the scientists to fill the research gap in temperature control inside the hive.

Different types of wood materials like bamboo, jack, *Callophylum sp.*, *Terminalia sp.*, *Tectona grandis* and *Bridelia sp.* were used to design stingless bee hive that control temperature inside the hive, based on available material and species of stingless bee. The hive material should be cheap, readily available, non-toxic to stingless bees and having less heat penetrating power. The wood material of the hive is important for bee colony establishment.

Chilli (*Capsicum annuum* L.) is an important vegetable crop grown in almost all the parts of tropical and subtropical regions of the world, belongs to the family Solanaceae. chilli is also known as cayenne pepper, hot pepper, American pepper, Chile, paprika and azi. The genus capsicum includes 30 species out of which *C. annuum* L., *C. frutescens* L., *C. pubescens* Ruiz & Pav. and *C. baccatum* L. are cultivated species in India (Bosland and Votava 2000; Wang and Bosland 2006).

Chilli is an often-cross pollinated crop. In India, chilli cultivated in a 30,900 ha area with production of 35,92,000 MT and with productivity of 11.62 MT/ha (NHB, 2018). Telangana is the major producing state in India followed by Karnataka and Madhya Pradesh.

The major problem of cultivation of chilli in the green house is poor pollination due to protected structure which results in low production and productivity (Kwon and Saeed, 2003). The problem of poor pollination in greenhouses can be overcome by keeping artificial bee colonies inside the greenhouses. Installing number of bee colonies in greenhouses depends on the type of bees and its flight range *i.e.* maximum distance travelled by bees for foraging so, estimating foraging distance of bees is necessary. In open field condition, pollination can be enhanced by keeping natural attractant like flowers and artificial attractants like sugar, jaggery (during off season) can be fed to the bees to increase natural bee population in the field.

Stingless bees are true generalists collecting vast nectar and pollen from the plants (Heithaus, 1979, Biesmeijer *et al.,* 2005). Stingless bees are good candidates for future alternatives in commercial pollination (Rindfleisch, 1980) as they can easily be kept in hives, have sufficient number of workers, and are non-aggressive (Roubik, 1995; Heard, 1999). *Heterotrigona itama* cockerell, is one of the potential candidates for commercial pollination in chilli (Salim *et al*. 2012).

The present work, flight range, colony characteristics and pollination efficacy of stingless bee, *Tetragonula travancorica* in chilli (*Capsicum annuum* L.). will strengthen the research concerning stingless bees and their pollination efficacy in chilli. The main objectives of this study are;

1. To study the flight range and colony characteristics of stingless bee *Tetragonula travancorica*.

2. To study the pollination efficacy of stingless bee *Tetragonula travancorica* in chilli.

Review of Literature

2. REVIEW OF LITERATURE

The literature pertaining to the flight range, colony characteristics and pollination efficacy aspects of stingless bees on Chilli are presented here.

2.1. FLIGHT RANGE

2.1.1. Standardization of food bait for stingless bees

Baiting stingless bees using pre-mix bait is a commonly accepted technique (Boontop *et al.,* 2008; Hannah *et al.,* 2012) with the assumption that all stingless bees are attracted to sugar. A recent study in Thailand showed that using 50% (v/v) honey solution was able to attract 12 species of stingless bees (Jongjitvimol and Petchsri, 2015). Kumara *et al.* (2016) reported that urine bait was found as an attractant compared to the pre-mixed bait, to five stingless bee species in a study conducted in Malaysia, while eight species were attracted to the pre- mixed bait compared to urine bait.

Lorenzon, and Matrangolo, (2005) in Brazil reported that eight among twelve stingless bees were attracted to the non-floral sources such as water, honeydew, seed, rotten fruit and resin compared to the floral sources. Boontop *et al*. (2008) in Thailand reported that honey was mixed with water in 1:1 ratio and used as a bait to attract stingless bees in different vegetation

Basari *et al.,* (2018) in Malaysia observed that more number of stingless bees were attracted to higher sugar concentration of 35 % and 50 % respectively compared to lower sugar concentration of 15 %. Among higher sugar concentration stingless bees prefer 50 % concentration in midday. 20-60 % nectar concentrations were preferred by Melipona bees.

2.1.2 Foraging distance of stingless bees

Different natural vegetation allows stingless bees to forage easily and potentially (Cartwright and Collett 1983; Plowright and Galen 1985). Smith *et al.,* (2017) observed in Australia that, minimum and maximum distance travelled by stingless bee was 333m and 712m respectively.

Silva *et al*., (2017) reported that *Melipona eburnea* Friese covers a radius of around 908 ha and able to cover foraging distance is 1.7km in relation to the hive

Maximum flight ranges of highly social bees found in lowland tropical forest. Pheromone trails were used for *Trigona* during foraging (Michener, 1974). Roubik, D.W. and Aluja, M. (1983) in Panama reported that maximum and minimum foraging distance of two species of stingless bees *Melipona* and *Trigona* in tropical forest is 2.4km, 1.65km 155m, and 505m respectively.

Van Nieuwstadt *et al.,* (1996) observed that maximum foraging distance of stingless bee species varies from 623 to 853m. Artificial nectar source differ from different stingless bee species and foraging number of *Trigona and Neotrigona* decreases with increased foraging distance.

Basari *et al.,* (2018) in Malaysia reported that the feeders kept at 1m distance had more numbers of bees compared to bees kept at 10m

2.2. HIVE PARAMETERS OF STINGLESS BEES

2.2.1. Brood area

Average brood volume of *Trigona mellipes* Friese, *T. sapiens* Cockerell and *T. clypearis* Friese, were 595, 224 and 464 mL respectively (Dollin *et al.* 1997). Halcroft

et al., (2013) observed in Australia that brood volume of *Trigona carbonaria* Smith, varied from 940 to 3535 mL and 1100 to 2550 mL in *Trigona hockingsi* Cockerell.

Portugal, (1963) reported that the nest of stingless bees consists of three areas namely brood area, area of old cerumen layers and area of pollen and honey pots. The brood area was about 18cm height by 14 cm diameter externally while internally 12cm by 9cm, difference is due to presence of involucrum of 4-10 waxy sheets. Maximum brood area was 13cm and a comb 10cm in diameter contain about 450 cells. The area of pollen and honey pots was seen laterally, average height and diameter of pot was 3 to 4cm and 2.5 to 3.2cm respectively. Generally, the pollen pots are seen closely to the brood area than honey pots. The brood area was surrounded by pollen pots and honey pots, each pot of 2.5cm in diameter and height, occasionally reaching 2cm wide and 4cm height. All the colonies consisted of food storage zone and brood zone internally. The food storage zone was divided to pollen and honey zone, both was placed separately, sometimes intermixed. The length and width of pollen pots varied from 6.04 to 8.63mm and 3.5 to 6.14mm and density of pollen pots ranged from 11-18 cells.

Dollin (1996) reported that the food pots resembled bunch of grapes and contained honey and pollen pots. The length and width of honey pots were 6.94 to 8.69mm and 3.64 to 6.03mm. Density of honey pots ranged from 2.9 to 4.9 cells.

Danaraddi (2007) reported that the length and width of pollen and honey pots of *Trigona irridipennis* was 7.26 and 4.49mm, 7.73 and 5.04 mm respectively. Danaraddi *et al.,* (2010) from Dharwad, Karnataka reported that length and width of pollen pots and honey pots varied from 6.04 to 8.63mm and 3.45 to 6.14mm, 6.86 to 8.70mm and 3.60 to 6.05mm respectively and density of pollen and honey pots ranged from 11 to 18 and 3.8 to 5.9 cells or 14 to 16 cells.

Patel and Pastagia, (2016) studied habitat and nesting behavior of *Tetragonula laeviceps* Smith, at Gujarat. The length and width of brood cells was 1.47 and 1.29mm

respectively, length of pollen and honey pots was 6.77 and 7.62mm and width of pollen and honey pots was 4.98mm and 4.75mm respectively. The density of brood cells, pollen and honey pots was 15, 13.50 and 4.85 cells.

Saufi and Thevan, (2015) reported in Malaysia that, internal nest of stingless bees consists of brood cells, honey pots and pollen pots. Honey and pollen were stored separately and arranged side by side. The height of brood cell, honey pots and pollen pots were 4.5mm, 23.28mm and 21.18mm respectively and diameter of brood cell, honey pots and pollen pots were 3.61mm, 11.91mm and 12.57mm respectively. The brood area, honey pots and honey pots were 250cm^2, 140cm^2 and 65cm^2 respectively.

Chinh *et al.,* (2005) observed that brood cells of *Liotrigona carpenteri* Engel, were 3 to 3.2mm long and 2.0 to 2.2mm diameter. Number of pollen and honey pots were 2 to 56 and 4 to145, respectively and height of honey pots and pollen pots were 7 to 7.2mm.

The brood area of *T. laeviceps* were described by Chinh *et al.,* (2005) observed that the height of pollen and honey pots were 5-7mm and 12-15mm respectively. Number of brood cells of *T. laeviceps* varied from 650- 3000 and total volume of pollen and honey pots was 1.0-5L

The internal structure of *Trigona ventralis* Smith, were described by Chinh *et al*. (2005) in Vietnam, brood cells of *T. ventralis* were 5-5.3mm long and 2.4mm diameter. Total number of brood cells varied from 659 - 43586. Storage food pots like honey pots and pollen pots were similar in shape and average volume of stored food varies from 0.4-3.7L.

Roubik (1979) observed that, nesting characteristics of different stingless bee species. Storage pot (honey pots and pollen pots) diameter of stingless bee *Trigona cilipes* Pellucida, was 0.7-1.0cm. Length and width of brood area was 8-13cm and 10-12cm respectively. Volume of honey pots and pollen pots was 281 and 60cm^3.

Diameter of storage pots of *Trigona pallens* Fabricius, was 0.9-1.0mm, brood area was 10-17cm long, 11-30cm breadth and volume of and pollen pots 52cm^3.

The internal nest characteristics of *Trigona williana* Friese was, diameter of honey as well as pollen pots was 1.2cm. Length and width of brood area was 9cm and 14cm respectively, and volume of honey pots and pollen pots was 77 and 27cm^3. Storage pot diameter of *Trigona hyalinata branneri* Lepeletier was 1.5cm and brood area was 6cm length and 4cm width. Internal nesting characteristics of *Trigona cupira* Smith was, brood area of 6cm long and 3.4cm breadth and the volume of honey pots and pollen pots was 63 and 63cm^3. Length and width of pollen and honey pots of *Trigona clavipes* Sakagami were 1.8 to 2.8cm and 3.0 to 4.5cm, and 2.1 to 3.5cm and 2.7 to 5cm. length and breadth of brood area was 9 to 18cm and 27 to 70cm respectively, and volume of honey pots and pollen pots was 1300 and 4485cm^3. Brood area of *Trigona dorsalis beebei* Smith was 9cm long and width of 30cm and volume of honey pots and pollen pots was 565 and 1202cm^3. Length and width of storage pots of *T. savannensis* Roubik was 1.1-1.8cm and 1.9-2cm and volume of honey and pollen pots were 44 and 26cm^3. Brood area characteristics of *T. tubiba* Smith was, length and breadth of pollen pots was 2.4cm and 2.9cm, brood area was 6cm length and 23cm width and volume of pollen and honey pots were 700 and 1565cm^3. Whereas *Melipona fulva* Lepeletier internal nesting characteristics was 1.6-3.5cm length and 3.2-4.7cm width of storage pots. Length and breadth of brood area was 7.8cm and 5.0cm respectively, and volume of honey and pollen pots were 156 and 29cm^3.

Pires *et al*. (2020) in Brazil observed that width and height of honey pot was 2.22-2.31cm, and 3.09-3.88cm and volume was 9.24 to15.58mL. Number of honey pots of *Melipona interrupta* (Cockerell) was 9.24 to 15.58. Height and width of Pollen pot was 76 to 4.85cm and 2.32 to 2.38cm respectively, and number of pollen pots was 3.82 to 9.96.

Dias *et al.,* (2008) reported average number of honey pots of *Melipona subtinida* Ducke was 55.43 through artificial feeding. Alves (2010) reported colonies of *Melipona scutellaris* had average honey pots of 14.96.

2.2.2 COLONY COMPOSITION

Roubik, (1983) studied nest and colony characteristics of stingless bees in Vietnam. He reveled the population of different stingless bee species. The total brood number of *T. capitata* Smith was 2521 - 7383 and number of adults was 400-1000. Total number of adult populations of *T. dorsalis* Smith was 1500 - 2000 and total brood number was 6433 - 8060. Total brood number of *T. nigra* Cresson was 1280-4090 and adult number was 400-600.Total adult population of *T. anustula* was 300 - 2000 and total brood population was 2662 - 12119. Total brood number of *T. leucogastra* Smith was 1025-1797 and total number of adult populations was 200-450. Total adult population number of *T. hypogea* Silvestri was 1200 - 3000 and brood population was16212-17367. Total number of adults of *T. nigerrima* Smith was 700 - 1800 and total brood number was 675 - 9838. Total brood population of *T. fulviventris* was 5395 - 9869 and total adult populations was 2000->10000. Total adult populations of *T. corvine* Cockerell was 20506-24854 and total brood number was 3822-36558.Total brood number of *T. fuscipennis* Friese was 17315- 20439 and total adult population was 5000-10000.Total brood number of *T. jatiformis* Cockerell was 917-3781 and total adult populations was 650-950. Total adult populations of *T. franki* Friese was 70-250 and total brood number was 212-342. Total brood population of *T.minima* were 88-380 and total adult population was 100-150. Total adult population of *T. latitarus* Bruguiere was 387-450 and total brood population was 1876-1972. Total adult populations of *T. onaticeps* was 1100-2400. Total brood population and adult populations of *T. isopterophila* Schwarz was 335-822 and 80-350. Total adult populations and brood number of *T. pectrolis* DallaTorre was 280-6457 and 379-19380.total brood population

and adult number of *T. pachysoma* Cockerell was 8601-12362 and 3000-10000.Total number of brood and adult population was 2400-2880 and 500-600. Total number of adult and brood population of *Melipona fasicata* Peletier was 895-3787and 200-1500.Total number of brood and adult population of *Melipona fuliginosa* Lepeletier was 515-2644 and 250-600.

2.2.3 PHYSICAL PARAMETERS

Torres *et al.,* (2007) worked on thermal investigations of stingless bee nest in Columbia. They observed temperature variations from brood area and storage area. Maximum brood area temperature recorded was 24.2 ± 2.6ºC when external air temperature was 17 to 22ºC.The temperature variation was almost similar in brood and storage area. Brood area showed decreased heat production due to temperature dropping in early morning hours. Honey bees have ability to maintain nest brood temperature between 33-36ºC when ambient temperature may reach below freezing or above 45ºC (Fahrenholz *et al.*1989). Average brood area temperature of *Trigona nigra paupera* and *Tetragonisca angustula* was 24.2±2.6ºC and 25.5 ±1.2ºC respectively, variations was due to nest architecture in both species.

Fletcher, (1981) observed thermoregulation in the brood area of stingless bee *Trigona denoiti*. The temperature at the center of the brood area was varied between 31 to 31.5ºC while the ambient temperature was 20 to 22 ºC. The temperature around hive was heated above 31.5 ºC till the center of the brood area reached 34.5 ºC. At this temperature the bees started running up and down at entrance tunnel. At 35.5 ºC the bees began to clog up the entrance tunnel it showed overheating of the nest. The average brood area temperature of *Trigona denoiti* Cockerell was between 31 and 32 ºC. The optimum brood area temperature of *Apis mellifera* Linnaeus was 34.5 ºC (Himmer 1927).

Torres *et al.* (2007) studied temperature changes inside the stingless bee hive *Tetragonisca angustula*. They noticed that the highest temperature recorded at the center of the brood area was 30.3±0.4 ºC and lowest temperature was 25.4±0.6 ºC whereas external air temperature was between 14 and 24ºC.

Brazilian stingless bee *Trigona spinipes* Fabricius able to maintain brood area temperature between 34.1 ºC and 36.0 ºC (Zucchi and Sakagami 1972). Roubik and Peralta (1983) observed that brood area temperature of *Melipona rufiventris* and *M. seminigra* was maintained at 31-32 ºC. *Scaptotrigona postica* Latreille was Brazilian stingless bee which maintain brood area temperature of 32±3ºC (Engels *et al*. 1995). Australian stingless bee *T. carbonaria* Smith, maintained its nest temperature at 24-29 ºC when external air temperature varied between 10and 23ºC (Amano *et al*. 2000).

Sung *et al*. (2008) studied thermal characteristics of Taiwan stingless bee *T. ventralis.* The maximum and minimum temperature recorded from storage pots was 24.8 ºC and 19.1 ºC and difference was 5.7 ºC which was nearly comparable to the temperature at the cavities inside the nest. Brood area temperature was varied between 24 ºC and 31ºC.

Moo-Valle *et al.* (2000) studied intranidal temperature fluctuation in *Melipona beecheii*. The brood area temperature from two stingless bee colonies was 27.1 and 25.6ºC respectively. The minimum brood area temperature recorded was 25.4ºC when ambient temperature was 22.9 ºC. Temperature inside the hive did not exceed above 34 ºC even external temperature was greater.

2.3 TEMPERATURE CONTROL INSIDE EMPTY BEE BOXES.

Saville *et al*. (2000) reported that the wood used for manufacture of hives were light weight, well-seasoned, good quality timber, termite free, resistant to rotting and wood should not have strong smell. The woods used was kail, teak and toon for Newton's hive. The warre hive was a hive and design was similar to Langstroth hive,

nadired was done without opening of the hive in order to retain inside heat. The hive was opened once in a year for harvesting to ensure constant internal temperature inside the hive.

Kasangaki *et al*., (2014) Observed the effect of hive design on internal hive temperature in Nepal. The Jumla hive was warmest at night but cool in the morning and jumla straw hive was warmest in a day followed by log top bar, log and newton hive. Nogueiro-Neto Hive and UTOB Hive was standardized hives for stingless bees, but in India traditional hives were using. Bees are kept in hollow logs,mud pots, bamboo pits, and wooden boxes. Commonly used wood for making hives were *Cordia*, *Terminalia ivorensis*, A. Chev. *Chorophora excels* Berg, *Piptadeniastrum africanum* Hook, *Markhamia lutea* Benth, *Ilex dipyrena* Wall, *Juglans regia* L. and *Pinus wallichii*.Akbar.

2.4. POLLINATION EFFICACY IN CHILLI (*Capsicum annuum* L.)

CHILLI

Palma *et al.*, (2008) in Kenya observed that flowers pollinated by *Hypotrigona gribodoi* Magretti, produced heavier fruits compared to self-pollination. Average number of seeds in the fruits of capsicum was higher compared to self-pollination. *Bombus impatiens* Cresson, was replaced by *Nannotrigona perilampoides* Cresson in greenhouses of *Capsicum chinense* Jacq, in Mexico (Palma *et al.,* 2008). The stingless bee *T. carbonaria* increased fruit weight of capsicum by 11% and number of seeds per fruit up to 34% compared to self- pollination in Australia (Occhiuzzi 2000).

In west Sumatera Putra *et al.,* (2016) conducted an experiment on pollination in chilli by *T. laeviceps* and *T. minangkabau* results were increased fruit set percentage by 9.66 and 12.32. It also increases seed number by 45.91% and 56.3%. Increase in fruit set and seed number automatically increases the number and weight of the fruit per plant.

Flowers pollinated by bees increase fruit yield than selfed ones. In some varieties of *capsicum* pollen grains was not fully released from the anthers hence external pollinating agents required for higher fruit set percentage and seed production (McGregor,1976). (Meisels *et al.*, 1997; Delaplane *et al.*, 2000) and had positive relation with number of fertilized ovules and seed number. Bee pollination not only increased fruit yield and also increases number of seeds per fruit. Cauich *et al.*, (2006) in Mexico observed that visit by bees increased the fruit set percentage in *capsicum annuum*

Putra *et al.*, (2014) in Indonesia observed that cross pollination improves pollination efficiency and quality of *capsicum*. Honey bee and stingless not capable to produce buzz pollination, they provide pollination in different ways to cause disturbances which improves buzz pollination (Raw, 2000 Jarlan, 1997).

Seed number was higher in flowers pollinated by *Austroplebia australis.* Increase in fruit size of *capsicum* due to increase in the pollen load (Rylski, 1973, Shipp *et al.*, 1994, Marcelis and Hofman-Eijer, 1997). Less sporadic foraging strategy of *T. carbonaria* is likely to be more suitable for improving fresh weight and grade of *capsicum* fruit. In Australia Greco *et al.* (2011) reported that *T. carbonaria* increases the quality of *capsicum annum*, fruit circumference and fresh and dry fruit weight. Whereas *Austroplebia australis* also increased weight of the fruit, fruit circumference and seed weight.

SOLANACEOUS VEGETABLES

Amano, K. (2004) Attempted stingless bees for pollination of crops in green house conditions in Japan and reported that *Trigona carbonaria* and *S. bipunctata* was effective pollinators of crops grown in glasshouse conditions in temperate countries. In tomato, *Trigona carbonaria* increased 8 % fruit set compared over control.

In Mexico, González-Acereto *et al.* (2006) have reported that pollination efficiency of *Nannotrigona perilampoides* in tomato and habanero pepper revealed that *Nannotrigona perilampoides* is an alternative pollinator to *A. mellifera* or bumble bees. Evaluation of *Meliponula beecheii* for pollination of habanero pepper in enclosures showed that it was efficient in pollinating this crop (González-Acereto *et al.*, 2006).

Nunes-Silva *et al*. in 2013, reported from Kenya, *Melipona fasciculata* was an efficient pollinator of *Solanum melongena*. *P*ollination of eggplants with stingless bees *Melipona fasciculata* increased fruit set percentage by 52.8% over control 20.3%. Bee pollination increases fruit weight by 96 % compared to control. postive effect of stingless bee pollination on quality and quantity of fruits was similar to that of *Bombus terrestris* pollination hence *M. fasciculata* was considered as alternative to bumble bees in green houses of Brazil.

Melipona spp. was efficient pollinators of economically important crops, including sweet pepper (Cruz *et al.*, 2005) and tomatoes (Sarto *et al*., 2005). Green house tomatoes were pollinated by *Melipona quadrifasicata* results in greater fruit yield and higher fruit quality than control Sarto *et al.* (2005). Santos *et al*., (2009) conducted an experiment on pollination efficacy of *A. mellifera* and *M. quadrifasicata* in tomato in brazil. The production of tomato was more from the green house with *M. quadrifasicata* compared to *A. mellifera* pollinated green house and control green houses. The weight of the fruit, circumference of the fruit and seed number is more in stingless bee pollinated greenhouse compared to control.

Materials and Methods

3. MATERIALS AND METHODS

The current study of flight range, colony characteristics and pollination efficacy of stingless bee, (*Tetragonula travancorica* Shanas and Faseeh,) in chilli (*Capsicum annuum L.*) was carried out in the Department of Agricultural Entomology, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala. The materials used, techniques adopted and the observations recorded in the current study are presented here.

3.1. FLIGHT RANGE

3.1.1. Standardization of Food Bait for Stingless Bee

The experiment was conducted in the playground at College of Agriculture, Vellayani, with an objective to standardize the food bait for stingless bees (Plate 1).

The materials used in an experiment were, live colony of stingless bees with less resources.

Treatments were - T_1- Sugar 35% concentration
T_2 - Sugar 50% concentration
T_3 - Sugar 75% concentration
T_4- Honey 35% concentration
T_5 - Honey 50% concentration
T_6 - Honey 75% concentration
T_7 - Jaggery 35% concentration
T_8 - Jaggery 50% concentration
T_9 -Jaggery 75% concentration
T_{10} – water

A. Treatments

B. Stingless bee hive

C. Layout of experiment

Plate 1. Standardization of food bait for stingless bee

The treatments were prepared by adding 350g, 500g and 750g of sugar, jaggery and honey in 1litre of water to prepare 35 %, 50 % and 75 % of sugar, jaggery and honey concentration.

Three feeder stands were placed 10m apart from the bee colony in south, west and east directions. The height of the feeder stands was maintained similar to the height of the stingless bee hive and all 10 treatments were placed above feeder stand and the stingless bees were allowed to feed on different food baits. The stingless bees were trained for a week for getting attracted to the food before conducting the experiment in the field. In field, the stingless bee colony was placed in the centre of experimental set up and observations on number of bees visiting different treatments were recorded.

3.1.2. Foraging Distance of Stingless bee.

The experiment was conducted at College of Agriculture, Vellayani to determine the foraging distance of stingless bee.

The best results obtained from the experiment 3.1.1 was used as attractant to determine the foraging distance of stingless bee. The sugar solution was kept on feeder stands at varying distances from 100m to 300m from the stingless bee hive with three replications. After 300m, food bait was progressively moved from 10 to 15 meters, up to 500m distance and the number bees attracted to food bait and the distance travelled by the stingless bee in meters was recorded.

3.2 STUDY OF HIVE PARAMETERS

The experiment was conducted at College of Agriculture, Vellayani to study the physical parameters of the stingless bee hives.

3.2.1. Brood area inside the hive

Brood area was recorded from 10 well maintained colonies and observations made are given below

1. Length of brood area (Cm)
2. Breadth of brood area (Cm)
3. Height of brood area (Cm)
4. Volume of brood area(Cm^3)
5. Number / volume of honey pots and pollen pots (L and Cm^3)

The observations on length, breadth and height were recorded with the help of a measuring scale in centimeters (cm) as shown in Plate 2. Volume was calculated with the help of a formula as given below. (Damara 2018)

Volume of brood area = length of brood area × breadth of brood area × height of brood area.

Volume of pollen pots and honey pots were calculated using the following formula.

$$Vs = 4/3\pi b^3$$

Or

$$Ve = b2\pi 2a/3$$

Where: Vs = the volume of sphere

Ve = the volume of an ellipsoid

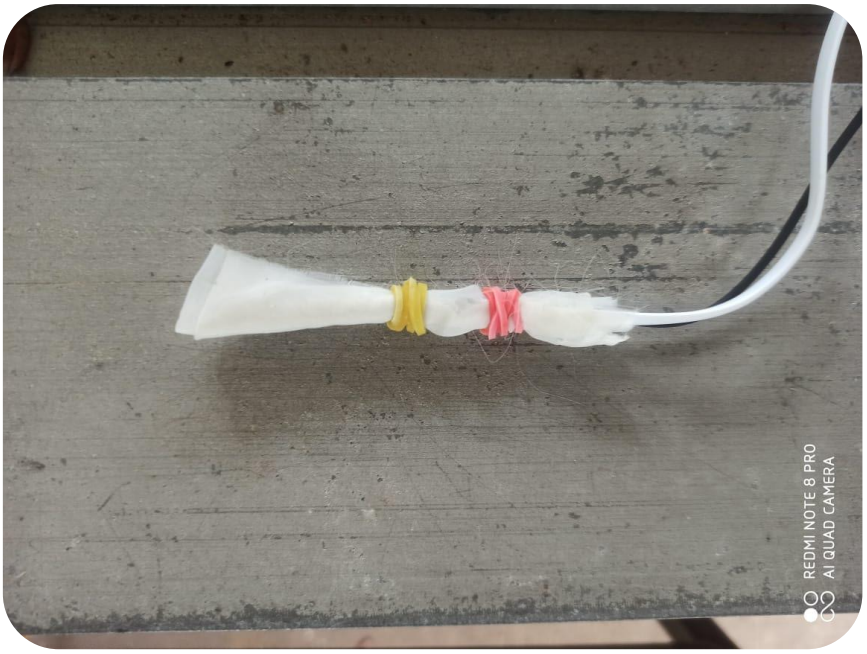
a = the longest radius of the ellipsoid (height of the storage pot) – 1/2 of its greatest diameter

b = ½ the greatest diameter of the storage pot.

Plate 2. Measuring brood area length

Plate 3. Counting of *Tetragonula travancorica* population

A. Sensors kept inside brood area



B. Sensors kept outside the hive (control)

Plate 4. Data-logger sensors being used to record hive parameters

3.2.2. Colony Composition

Ten well maintained stingless bee colonies were used for conducting this study at the College of Agriculture Vellayani.

Colony composition was determined by counting different members of the colony with the help a device called suction trap, which works on suction pressure. The bees from the colony was sucked off in to the trap. Later suction trap was connected to a tube/ pipe, and by releasing bees through the pipe in to air / atmosphere the bees were counted.

Another method to count the population of the colony was by making sound on the stingless hive. Due to disturbance, the bees started coming out from the hive. The bees were collected in bottle at the entrance of the hive as shown in plate 3. The collected bees were transferred to small tube-like structure and by releasing the bees from the tube to the air/ atmosphere, population of bees were counted.

3.3.3. Physical Parameters

The physical parameters like temperature and relative humidity were recorded from the brood area of four well maintained colonies with the help of data loggers. The procedure to record physical parameters from stingless bee hive are given below. Elitech data logger software was used to interpret the data.

Temperature and humidity sensors were placed inside the brood area of the hive to record the data along with one control as shown in plate 4.

3.3. TEMPERATURE CONTROL INSIDE EMPTY BEE BOXES.

The experiment was conducted to determine the temperature control inside different wood types.

Design: Completely Randomized Design Treatments: 4 Replications: 4

Treatments - T_1 - *Tectona grandis* L.

T_2 - *Artocarpus* sp., Lam.

T_3- *Bridelia* sp. Baill.

T_4 - *Terminalia* sp., L.

Four different wood types were used to construct stingless bee hives.

The temperature and humidity sensors were kept inside the hives and the hives were sealed with propolis. Before keeping data logger inside the hive, parameters like temperature and humidity were set with the help of Elitech data logger software for recording the data.

After parameters were set, the data logger was started by holding power button for few seconds. It was placed inside the hive and the hive was sealed with natural propolis. All wood types along with data logger was placed inside hot air oven at 40°c for 3 hrs. As shown in plate 5. After 3hrs the wood types was taken out and procedure to record the data is given below.

1. Connect the data logger to the computer and open Elitech software
2. Click on the summary, table, graph and summary to display recorded data
3. Click on the table to display recorded data
4. Click on the graph to display recorded data
5. Click on the export button on the displayed table or graph
6. Small table of pdf, excel and word documents were displayed
7. The pdf, excel or word format could be used to save the recorded data.
8. Recorded data was analyzed after saving to the computer hard drive.

Statistical analysis

The recorded data was subjected to statistical analysis with WASP 2.0. software. The design used was, Completely Randomised Design. The data was further analysed and tabulated.

A. Four different wood types

B. Data loggers

C. Hives being exposed inside hot air oven at 40°C

Plate 5. Temperature control inside empty bee boxes

3.3. POLLINATION EFFICACY OF STINGLESS BEE (*Tetragonula travancorica)* IN CHILLI

The research was carried from August 2019 to December 2019, on pollination efficacy by stingless bees on chilli at Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala.

The crop was raised based on package of practices recommended by Kerala agricultural university (KAU, 2016) in open field conditions.

Design – CRD Treatments - 3 Replication – Five

Treatments – T_1 - Open pollination,

T_2 - Self-pollination

T_3 - Stingless bee pollination

There were 5 plants per replicate and overall, 75 chilli plants were raised for this study. The experimental plot was divided into three equal parts. One part was occupied by open pollination treatment and other two parts by self-pollination and stingless bee pollination respectively. In open pollination treatment, the chilli plants were allowed for open pollination. In self-pollination treatment the chilli plants were bagged with selfing bags untill fruit set to prevent the flowers from being pollinated by other pollinating agents. In stingless bee pollination treatment, closed structure was constructed in the open field, two strong stingless bee colonies of *T. travancorica* were placed and following observations were recorded.

1. Number of flower buds per plant
2. Number of flowers per plant
3. Number of fruits per plant
4. Yield per plant

$$\text{Pollination efficiency} = \frac{\text{Total numbers of flowers that produce fruits}}{\text{Total numbers of observed flowers}}$$

Statistical analysis

The data collected from the field experiment were subjected to statistical analysis using WASP 2.0 software.

Results

4. RESULTS

In the present study, food bait was standardized for attracting stingless bees and foraging distance of stingless bee was estimated. Brood area characters such as length, breadth and height of brood area, volume of brood structure, volume of honey and pollen pots were measured. The colony strength of queen and workers from 10 different stingless bee hives were determined. Brood area temperature from four stingless bee hives were recorded. The best wood types to control temperature inside the hive was identified and effect of stingless bee in pollination of chilli was studied. The results obtained from all above mentioned experiments is discussed in this chapter.

4.1. FLIGHT RANGE

4.1.1 Standardization of food bait for stingless bees

Among all the food baits, the most preferred food bait by stingless bee was 35 % sugar concentration with average number of 18 bees visiting, followed by 35 % honey concentration with 14 number of bees, which was on par with 35 % sugar concentration. The remaining treatments such as sugar 50 % and 75 % concentration, Jaggery 35 %, 50 % and 75 % concentration and honey 50 % and 75 % concentration was on par with 35 % honey concentration as shown in Table 1.

4.1.2 Foraging distance of stingless bee

The result obtained from the experiment outlined in 4.1.1 was used as attractant *i.e.* 35 % sugar concentration, was prepared by dissolving 35g of sugar in 100ml of water, to determine the foraging distance of stingless bees. The food bait of 35 % sugar concentration was kept at different distances varying from 100m to 500m respectively. The distance travelled by stingless bee in meters and number of bees attracted to 35 % sugar concentration was recorded.

Distance travelled by stingless bee

TABLE 1. STANDARDIZATION OF FOOD BAIT FOR STINGLESS BEES

Treatments	Number of bees visited
Sugar 35% concentration	18[a]
Sugar 50% concentration	12.6[b]
Sugar 75% concentration	12[b]
Jaggery 35% concentration	12[b]
Jaggery 50% concentration	10.3[b]
Jaggery 75% concentration	11[b]
Honey 35% concentration	14[ab]
Honey 50% concentration	10.6[b]
Honey 75% concentration	9.6[b]
Control (water)	5[c]
CD (0.05)	4.612

The distance travelled by stingless bee varied from 100m to 400m. Maximum distance travelled was 400m and minimum distance travelled by stingless bee was 100m.

The present study was conducted with three replications. In one replication, bees reached up to 400m and in another two replications, bees reached up to 350 and 385m respectively. The average distance travelled by stingless bees was 378 meters.

Number of bees at food bait

The maximum number of bees were attracted to 35 % sugar concentration with 28 numbers at 100m distance followed by 200m and the least number of bees were observed at 400m distance with 19 numbers.

From table 2, it can be inferred that the distance travelled by bees decreased when foraging distance increased *i.e.* the number of bees were more at 100m distance than at 400m. Twenty-eight bees were observed at 100m distance followed by 26 number of bees at 200m distance and 19 number of bees at 400m distance.

4.2. Study of hive parameters

4.2.1. Brood area inside the hive

Brood area inside the hive recorded from 10 well maintained stingless bee colonies are listed in Table 3 and few hives are shown in plate 6.

Internal nesting characteristics including brood area parameters such as length, breadth and height of brood area, volume of brood structure and storage pots including pollen pots and honey pots are shown in plate 7.

Length of brood area

The length of brood area varied among all 10 stingless bee hives. Highest brood area length was observed in stingless bee hive-1 (16cm) followed by stingless

TABLE 2. FORAGING DISTANCE OF STINGLESS BEE

Treatments	Number of bees at food bait
100m	28[a]
200m	26[b]
300m	21[c]
400m	19[d]
500m	0
CD (0.05)	3.01

TABLE 3- BROOD AREA INSIDE THE HIVE

Stingless bee hives	Length of brood area	Breadth of brood area	Height of brood area	Volume of brood area
HIVE -1	16cm	12cm	12cm	592 cm^3
HIVE -2	10cm	7.5cm	9cm	675 cm^3
HIVE -3	15cm	8cm	8.5cm	1020 cm^3
HIVE -4	12cm	8cm	7cm	672 cm^3
HIVE -5	15cm	9cm	8.5cm	1147.5 cm^3
HIVE -6	10cm	6.5cm	8cm	520 cm^3
HIVE -7	11cm	7cm	6cm	462 cm^3
HIVE -8	9cm	8cm	5cm	360 cm^3
HIVE -9	6cm	4cm	4cm	96 cm^3
HIVE -10	10.5cm	8cm	6cm	504 cm^3

A. Brood area inside the stingless bee hive -2

B. Brood area inside the stingless bee hive- 9

Plate 6. Brood area inside different stingless bee hives

A. Brood area of stingless bee

B. Pollen and honey pots

Plate 7. Internal nesting characteristics of *Tetragonula travancorica*

bee hive -5 and 3 (15cm) and shortest length of brood area (6cm) was observed in stingless bee hive -9.

Breadth of brood area

The breadth of brood area varied from 4 to 12cm among ten stingless bee hives. Stingless bee hive -1 had 12cm of brood area breadth followed by stingless bee hive -5 with 9cm and minimum breadth of brood area of 4cm was observed in stingless bee hive-9.

Height of brood area

The height of brood area was recorded from 10 well maintained stingless bee hives. Maximum height of brood area (12cm) was recorded from stingless bee hive-1 followed by stingless bee hive-2 with 9cm and the least height of 4cm was recorded from stingless bee hive-9.

Volume of brood structure

Volume of brood structure was calculated by multiplying length, breadth and height of brood area from 10 well maintained stingless bee hives. The volume of brood varied from 96 to 1147.5 cm^3. The highest volume of brood area was observed from stingless bee hive -5 with 1147.5 cm^3 followed by stingless bee hive -3 with 1020cm^3 and the least volume (96cm^3) of brood area was recorded from stingless bee hive -9.

Volume of food storage pots

The stingless bees foraged and collected their food resources like pollen, honey and propolis which was stored in specialized pot like structures called food storage pots. It included honey pots and pollen pots. The shape of the honey pots and pollen pots varied among different stingless bee hives. Generally, shape of food pots was oval or spherical.

Volume of food pots varied among all 10 stingless bee hives. The volume of pollen pots were greatest in stingless bee hive -5 with 105cm^3 followed by hive -2 with 96cm^3 and the least volume of pollen pots were recorded from stingless bee hive -9 with 21cm^3 (Fig - 1). The volume of honey pots were recorded in litres and varied from 0.021L to 0.25L. Highest volume was recorded from stingless bee hive-5 followed by hive - 4 with 0.0195L and the least volume of honey pot was recorded from stingless bee hive -3 as shown in Fig 2.

4.2.2 Colony composition

The colony composition was obtained by counting different members of the colony like queen and workers, from 10 well maintained stingless bee hives at College of Agriculture, Vellayani. It was done with the help of a device called suction trap. The bees trapped inside the bottle were counted while releasing them outside. The observations recorded are listed in table 4.

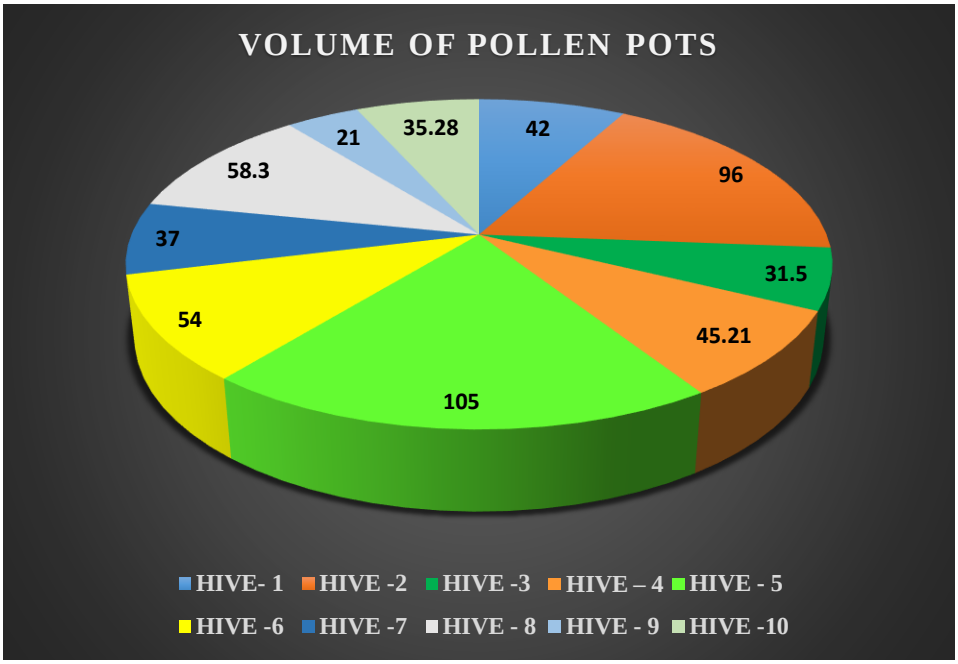
The results obtained indicate that, all the ten stingless bee hives had only one queen bee whereas, the strength of the workers varied from hive to hive. The maximum strength of workers (3255) were observed in stingless bee hive -5 followed by stingless bee hive -10 (2648) followed by stingless bee hive -8 (2330) and the least number of workers were observed in stingless bee hive -1 with (700 numbers) as shown in Fig 3.

4.2.3 Physical parameters.

The physical parameters like temperature and relative humidity were recorded from brood area of four stingless bee hives with the help of data loggers. The observations recorded were, temperature and relative humidity of brood area. The data loggers were installed in brood area of all four stingless bee hives. The maximum and minimum temperatures recorded were 33 ºC and 22.9 ºC respectively.

TABLE 4. POPULATION COUNT OF STINGLESS BEES

Stingless bee hives	Number of queen	Number of workers
HIVE -1	1	700
HIVE- 2	1	1457
HIVE- 3	1	954
HIVE- 4	1	1540
HIVE- 5	1	3255
HIVE- 6	1	2102
HIVE- 7	1	1310
HIVE- 8	1	2330
HIVE- 9	1	741
HIVE- 10	1	2648



* Volume of pollen pots in cm^3

Fig 1. Volume of pollen pots from 10 Stingless bee hives

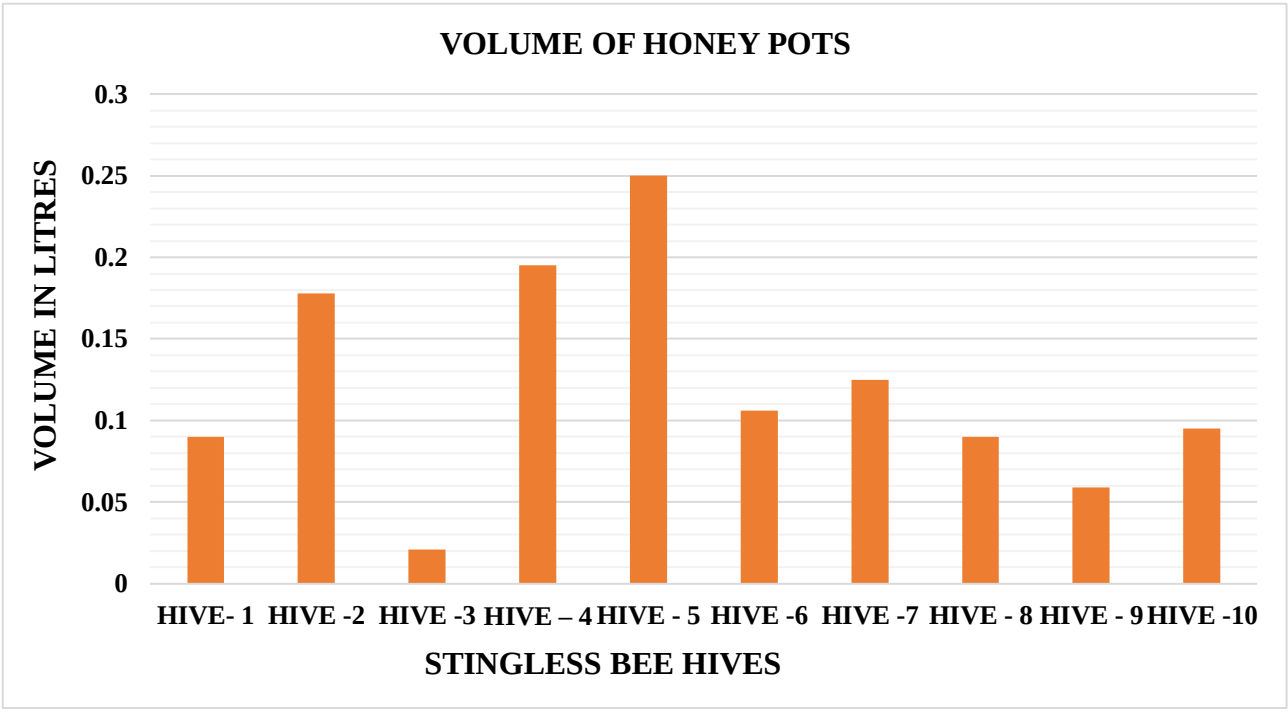


Fig 2. Volume of honey pots from 10 stingless bee hives

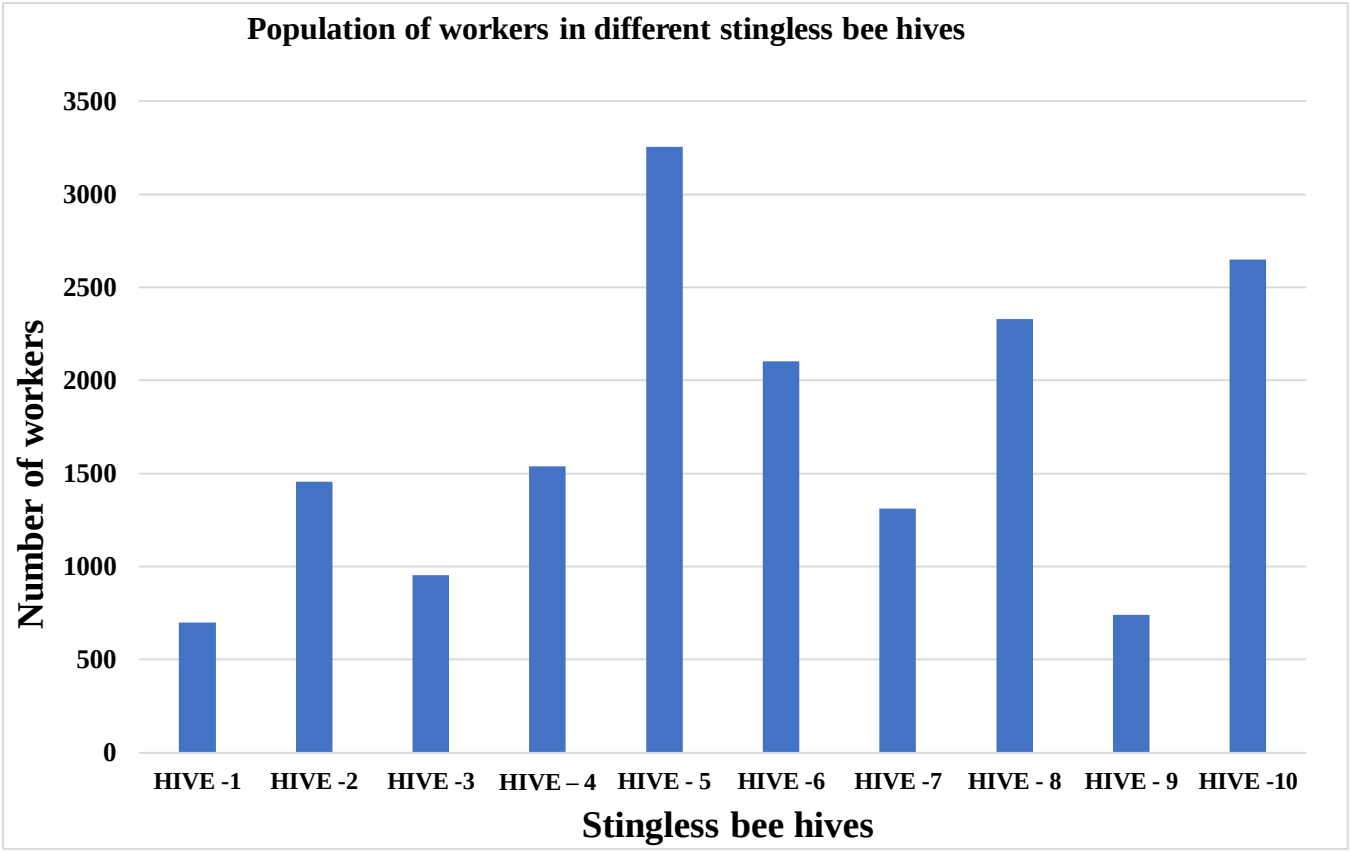


Fig 3. Population of workers in different stingless bee colonies.

The fluctuations observed in air temperature varied between 24.1 ºC and 33.4 ºC. The average minimum and maximum brood area temperature recorded from four stingless bee hives were 23.32 ºC and 32 ºC as shown in table 5. The minimum and maximum relative humidity recorded from the brood area of were 71.7% and 93.3% while the relative humidity in atmosphere was 73.1% and 98.1% respectively. The average minimum and maximum humidity recorded was 78.67% and 89.1% respectively.

4.3 TEMPERATURE CONTROL INSIDE EMPTY BEE-BOXES

In order to determine the temperature fluctuation inside the hives made out of different wood types, the following experiment was carried out. The four commonly used wood types viz., *T. grandis*, *Artocarpus sp*., *Bridelia sp*. and *Terminalia sp*., were used to make stingless bee hives and they were exposed to 40ºc in hot air oven for 3 hrs and parameters like temperature and humidity inside the hives were recorded with the help of data loggers, which were kept inside the hives along with temperature and humidity sensors.

The analyzed results are presented in Table 6. Among all four wood types, hives made of *bridelia* was found to be the best wood type that could control temperature inside the hive (average temperature of 39.56 ºC) followed by *Terminalia* with 38.2ºC followed by teak with 35.62ºC and jack with 31.86ºC (Table 6). The time trend of hive made of jack which took very less time to reach 40ºC as shown in Fig 4. followed by teak in Fig 5. followed by *Terminalia* (Fig 6), and finally, hive made up of *Bridelia* took more time to reach 40ºC (Fig 7).

4.4 POLLINATION EFFICACY IN CHILLI (*Capsicum annuum* L.)

The study on pollination efficacy of stingless bee in Chilli was conducted at Instructional farm, College of Agriculture, Vellayani. The experimental plot was divided into three equal parts, one for self-pollination and another two parts for open pollination and stingless bee pollination treatments. The Chilli crop was raised in all three treatments and pollination efficacy was tested.

The observations on number of flower buds per plant, number of flowers per plant, number of fruits per plant, yield per plant in kg and percentage fruit set was recorded from all three treatments.

Number of flower buds and flowers

There was no significant difference in the number of flowers buds and number of flowers among treatments of stingless bee pollination, open and self-pollination.

Number of fruits and yield per plant

Significant difference was observed between number of fruits per plant and yield per plant (kg) among the treatments. Number of fruits per plant was highest in stingless bee pollinated treatment followed by open pollination and less in self-pollinated treatment with average of 80, 68 and 59 number of fruits per plant respectively (Table 7). Yield per plant was highest in stingless bee pollinated crop followed by open pollinated and least in self-pollinated plants with an average yield was 0.81kg, 057kg and 0.48kg respectively.

Weight of the fruit and percent fruit set

Significant difference in weight of the fruit among the treatments were observed. Weight of the fruit was more in stingless bee pollinated plants compared to open and self-pollination with an average weight of 10.08g, 8.48g and 8.41g respectively. Pollination efficiency was maximum in stingless bee pollination treatment followed by open and self-pollination treatments with average fruit set p of 82.74%, 69.69% and 62.41% respectively. The percentage increase in yield was 42 percentage increase in fruit number and weight of the fruit was 18.1% and 18.8% respectively over the control (self-pollination) (Table 8).

TABLE 5. TEMPERATURE AND RELATIVE HUMIDITY INSIDE BROOD AREA

Stingless bee hives	Minimum temperature in ºC	Maximum temperature in ºC	Minimum RH (%)	Maximum RH(%)
HIVE -1	23.6	33	73.4	79.6
HIVE -2	23.5	32.6	71.7	93
HIVE -3	23.3	29.5	84.4	92.2
HIVE – 4	22.9	32.6	85.2	93.3
Control	24.1	33.4	73.1	98.1
Average	23.32	32	78.67	89.5

TABLE 6. EVALUATION OF TEMPERATURE CONTROL INSIDE THE HIVE

Treatments	Temperature
Jack	31.860[d]
Teak	35.620[c]
Terminalia	38.220[b]
Bridelia	39.560[a]
CD(0.05)	1.167

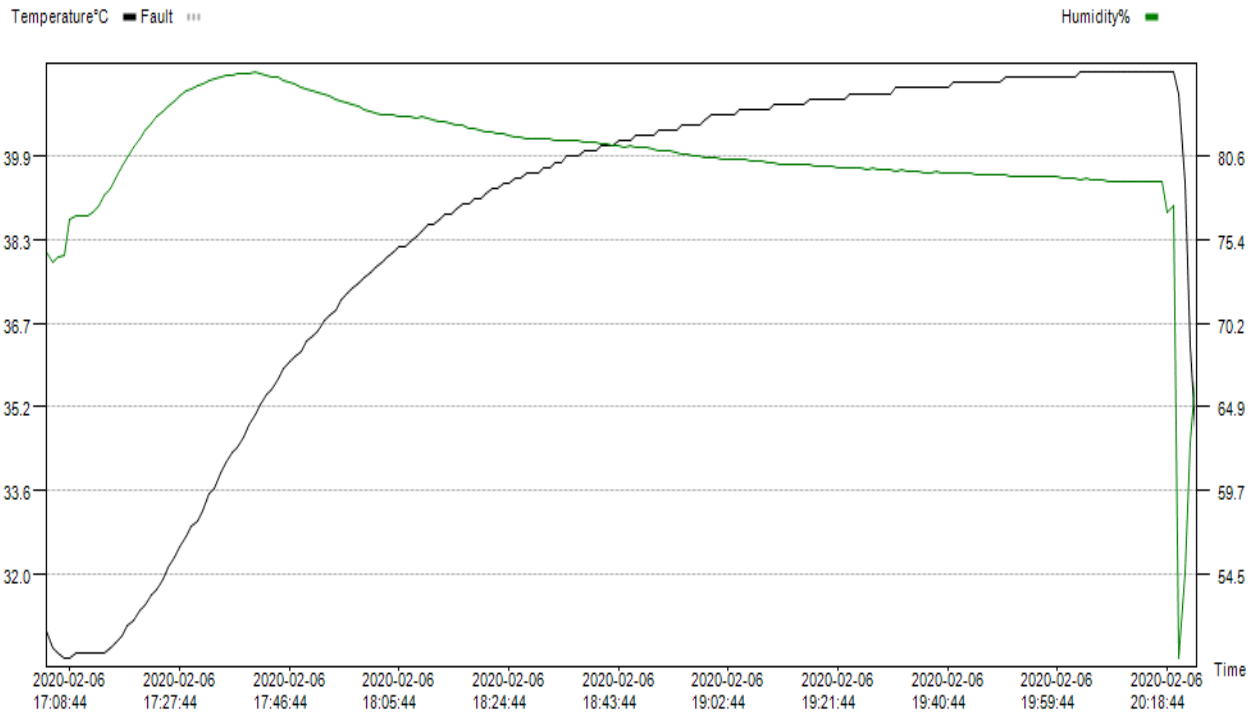


Fig 4. Time trend followed by jack hive to reach 40°C

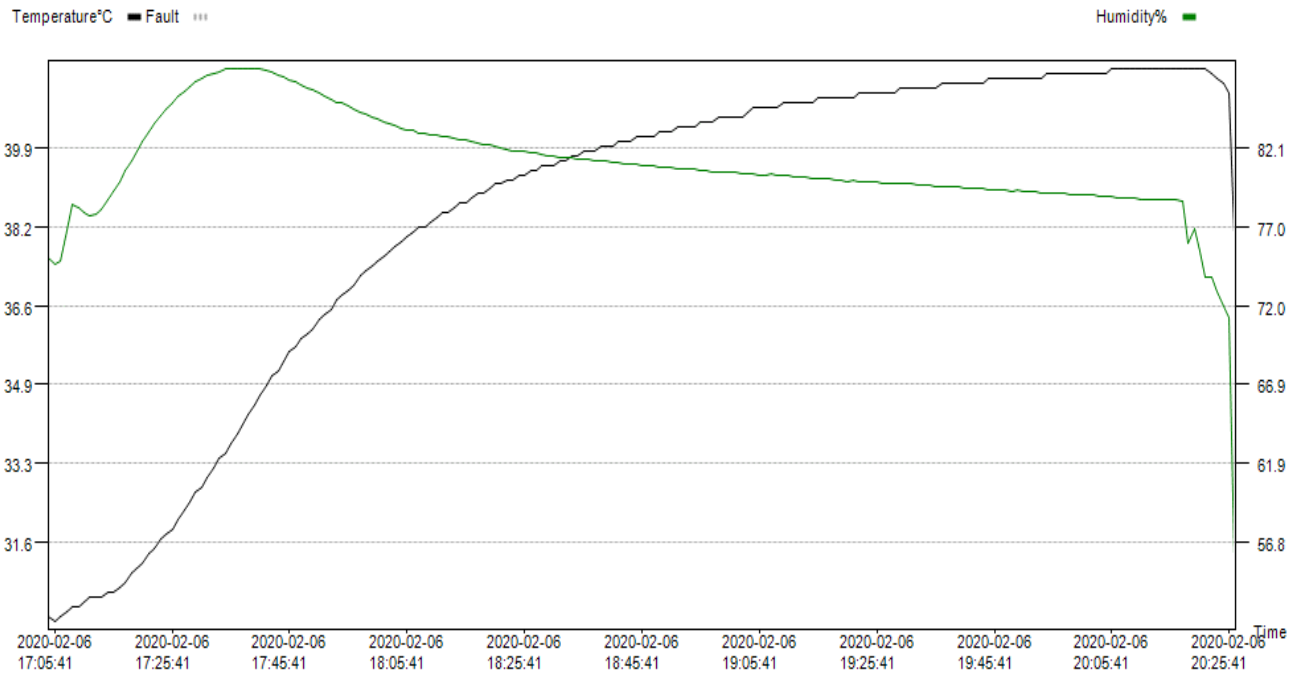


Fig 5. Time trend followed by teak hive to reach 40°C

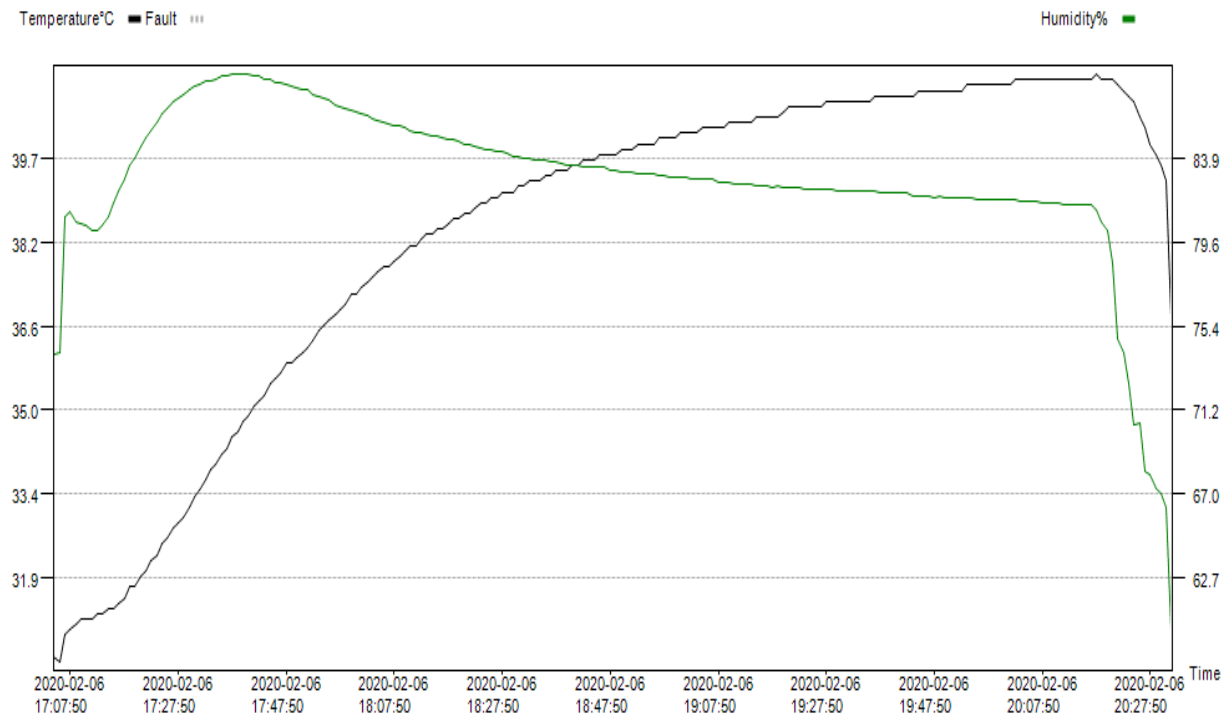


Fig 6. Time trend followed by Terminalia hive to reach 40°C

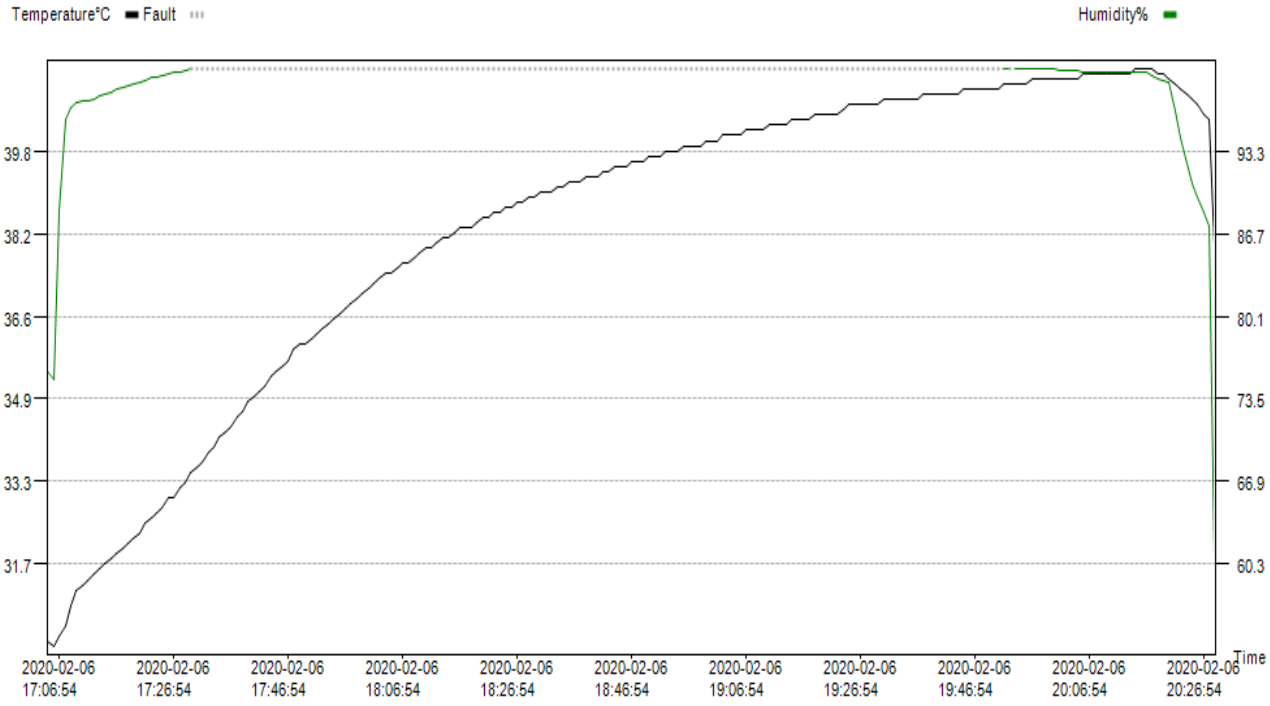


Fig 7. Time trend followed by Bridelia hive to reach 40°C

4.4 POLLINATION EFFICACY IN CHILLI (*Capsicum annuum* L.)

The study on pollination efficacy of stingless bee in Chilli was conducted at Instructional farm, College of Agriculture, Vellayani. The experimental plot was divided into three equal parts, one for self-pollination and another two parts for open pollination and stingless bee pollination treatments. The Chilli crop was raised in all three treatments and pollination efficacy was tested.

The observations on number of flower buds per plant, number of flowers per plant, number of fruits per plant, yield per plant in kg and percentage fruit set was recorded from all three treatments.

Number of flower buds and flowers

There was no significant difference in the number of flowers buds and number of flowers among treatments of stingless bee pollination, open and self-pollination.

Number of fruits and yield per plant

Significant difference was observed between number of fruits per plant and yield per plant (kg) among the treatments. Number of fruits per plant was highest in stingless bee pollinated treatment followed by open pollination and less in self-pollinated treatment with average of 80, 68 and 59 number of fruits per plant respectively (Table 7). Yield per plant was highest in stingless bee pollinated crop followed by open pollinated and least in self-pollinated plants with an average yield was 0.81kg, 057kg and 0.48kg respectively.

Weight of the fruit and percent fruit set

Significant difference in weight of the fruit among the treatments were observed. Weight of the fruit was more in stingless bee pollinated plants compared to open and self-pollination with an average weight of 10.08g, 8.48g and 8.41g respectively. Pollination efficiency was maximum in stingless bee

pollination treatment followed by open and self-pollination treatments with average fruit set p of 82.74%, 69.69% and 62.41% respectively. The percentage increase in yield was 42 percentage increase in fruit number and weight of the fruit was 18.1 and 18.8 respectively over the control (Table 8).

TABLE 7. POLLINATION EFFICACY OF STINGLESS BEE (*Tetragonula travancorica*) IN CHILLI

Treatments	Number of flower buds/plant	Number of flowers/plant	Number of fruits /plant	Yield /plant in kg	Percent fruit set	Weight of the fruit (g)
Open pollination	115.2	97.8	68.20[b]	0.571[b]	69.698[b]	8.48[b]
Self-pollination	114.4	95.0	59.40[c]	0.485[c]	62.416[c]	8.14[b]
Stingless bee pollination	114.8	97.4	80.60[a]	0.811[a]	82.744[a]	10.08[a]
CD (0.05)	NS	NS	6.28	0.66	4.5	1.16

TABLE 8. COMPARISON OF STINGLESS BEE TREATMENT OVER CONTROL

Parameters	Percent control over increase
Yield per plant in kg	42.1
Fruit number per plant	18.1
Fruit weight	18.8

A. Stingless bee pollinating chilli flowers

B. View of stingless bee pollinating chilli

Plate 8. Stingless bee pollinating chilli flowers

Discussion

5. DISCUSSION

The results of the study on flight range, colony characteristics and pollination efficacy of stingless bee in chilli are discussed in this chapter.

5.1 FLIGHT RANGE

5.1.1 Standardization of food bait for stingless bees

The current study revealed that the artificial food bait preferred by stingless bees was 35 % sugar which was on par with 35 % honey. Similarly, Kumara *et al.* (2016) reported that eight species of stingless bees were attracted to the pre- mixed sugar bait. Baiting stingless bees using pre-mix bait is a commonly accepted technique (Boontop *et al.,* 2008; Hannah *et al.,* 2012) with the assumption that all stingless bees are attracted to sugar, Jongjitvimol and Petchsri (2015) also reported that 50% (v/v) honey solution was able to attract 12 species of stingless bees. Basari *et al* (2018) in Malaysia reported that more number of stingless bees were attracted to higher sugar concentration of 35 % and 50 % compared to lower sugar concentration of 15 %.

2.1.2 Foraging distance of stingless bees

The present study, the foraging distance of stingless bee was estimated to be 387m. The results obtained by Roubik *et al.,* (1983) in Panama where, the minimum and maximum foraging distance of stingless bee *Trigona* in tropical forest was 155m, and 505m respectively. The minimum and maximum foraging distance of stingless bee (T. *travancorica*) was found to be 100m and 387m respectively. Van Nieuwstadt *et al.,* (1996) observed that maximum foraging distance of stingless bee species varied from 623 to 853m. which is higher than the foraging distance of T. *travancorica*. More number of bees were recorded from shortest distance of 100m (28 no's) and least number (19 no's) were recorded from largest distance of 400m which is similar to the results of Van Nieuwstadt *et al.,*

(1996) and Basari *et al.,* (2018). The feeders kept at 1m distance had more numbers of bees compared to feeders kept at 10m.

5.2 STUDY OF HIVE PARAMETERS

5.2.1 Brood area inside the hive

Internal nesting characteristics of *T. travancorica* were studied, which includes brood area and storage pots. Brood area includes brood cells and storage pots includes pollen pots and honey pots.

In the present study, the brood area length, breadth and height of *T. travancorica* varied between 6cm to 16cm, 4cm to 12cm and 4cm to 12cm respectively. Volume of brood area, volume of pollen and honey pots varied between 96 cm^3 to1147.5 cm^3, 21cm^3 to 105cm^3 and 0.021L to 0.250L respectively. Dollin *et al.* (1997) observed that, average brood volume of *T. mellipes, T. sapiens* and *T. clypearis* were 595, 224 and 464 ml respectively. Saufi, and Thevan (2015) reported brood area, honey pots and honey pots area of *G. thoracica* to be 250cm^2, 140cm^2 and 65cm^2 respectively. Roubik (1979) also reported nesting characters of *T. cilipes,* which includes length and width of brood area which was 8-13cm and 10-12cm respectively. Volume of honey pots and pollen pots was 281 and 60cm^3.

Internal nest characteristics like length, breadth, height, volume of brood area, volume of pollen pots and honey pots etc. were similar in the stingless bee species *T. williana, T. hyalinata branneri, T. cupira, T. dorsalis beebei, T. savannensis, T. tubiba* and *Melipona fulva* when compared to internal nesting characters of *T. travancorica*.

5.2.2 COLONY COMPOSITION

In this current study, colony composition of *T. travancorica* worker's population varied from 700 - 3255 numbers which are similar to the population of *T. dorsalis, T. angustula, T. hypogea, T. nigerrima, T. onaticeps* and *Melipona fasicata.* Population of *T. capitata, T. nigra, T. jatiformis, T. franki, T. aff. Minima,*

T. latitarus, T. isopterophila and *M. fuliginosa* was lower compared to population of *T. travancorica. T. pachysoma, T. pectrolis, T. fuscipennis, T. corvine, T. fulviventris* populations were higher compared to *T. travancorica* as reported by Roubik, (1983).

5.2.3 PHYSICAL PARAMETERS.

The physical parameters like temperature and relative humidity were recorded from brood area of four stingless bee hives with the help of data loggers. The fluctuations observed in air temperature varied between 24.1 ºC and 33.4 ºC. The average minimum and maximum brood area temperature recorded from four stingless bee hives were 23.32 ºC and 32 ºC. The maximum brood area temperature is similar to observations made by Roubik and Peralta (1983), who found out that the temperature in the brood area of *M. rufiventris* and *M. seminigra* nests is maintained at 31-32°C, probably by heat generated by the mass of larvae. *M. beecheii, M. fuliginosa Lepeletier* and *Partamona cupira* (Smith) maintain nest temperatures at 23-30°C (Wille 1976, Moo-Valee *et al.*, 2000). This coincides with larger fluctuations similar to current study on *T. travancorica*. These facts suggest that, preferable temperatures in the brood area is being maintained by the stingless bees.

5.3 TEMPERATURE CONTROL INSIDE EMPTY BEE-BOXES

In order to determine the temperature fluctuation inside the boxes made out of different wood types, the following experiment was carried out. The four commonly used wood type's viz., *T. grandis*, *Artocarpus* sp., *Bredelia* sp. and *Terminalia* sp., were used to make stingless bee boxes and they were exposed to 40ºc in hot air oven for 3 hrs. and parameters like temperature and humidity inside the boxes were recorded with the help of data loggers, which were kept inside the hives along with temperature and humidity sensors.

Sung *et al.*, 2008 opined that, in natural hives, thermostatic effect helps thermoregulation, where the wood insulation along with shades are able to keep the

temperature of the hive relatively constant. Among all four wood types, boxes made of *Bridelia* was found to be the best wood type that could control the inside temperature, followed by *Terminalia* with 38.2ºC followed by teak with 35.62ºC and jack with 31.86ºC. The results indicate that, *Bridelia*. wood should be preferable used to construct bee boxes for stingless bees.

5.4. POLLINATION EFFICACY IN CHILLI (*Capsicum annuum* L.)

Pollination is a mutualist relation between plant and pollinators. The pollinators will go in search of nectar and in turn they pollinate plants in many of cross, often cross pollinated plants and rarely self-pollinated plants. Majority of solanecous species are self-pollinated crops while Chilli is considered as often cross pollinated plant and there are high chance of pollination by insects from 5-33%.

Chilli pollinated by stingless bee *T. travancorica* showed increased fruit yield similar to the results obtained by Cauich *et al.,* 2006. Meisels *et al.,* 1997; Delaplane *et al.,* 2000 observed increased fruit yield and percentage fruit set in *Capsicum chinensis and Capsicum annuum* by stingless bees. Occhiuzzi (2000) reported that *T. carbonaria* increased fruit weight of *Capsicum* by 11%

The stingless bee, *T. travancorica* increased fruit set by 32.2% in Chilli over self-pollination treatment similar to the results obtained by Putra *et al.* (2014) who reported that, cross pollination improves the fruit set percentage and quality of *Capsicum*. de Oliveira Cruz *et al.* (2005) Rold´an Serrano and Guerra Sanz (2009) and Al-Abbadi (2006). Putra *et al.,* (2016) observed increased fruit set percent by 9.66 % and 12.32% in *T. laeviceps* and *T. minangkabau* respectively.

From the above discussion, it can be inferred that stingless bees are efficient pollinators of chilli. Hence, stingless bees are valuable bio-resource that can be successfully employed for enhancing crop yield and quality of produce.

Summary

6. SUMMARY

The study on “flight range, colony characteristics and pollination efficacy of stingless bee *Tetragonula travancorica* in chilli” was conducted at instructional farm and Department of Agricultural Entomology, College of Agriculture Vellayani, with an objective to study the flight range, colony characteristics and pollination efficacy. Flight range of *T. travancorica* was determined with the help of standardized food bait. Colony characteristics like brood structure, storage pots and population of queen and workers was estimated from the 10 well maintained stingless bee colonies and physical parameters like temperature and relative humidity of brood area was recorded from four stingless bee hives. Pollination efficacy of stingless bee in chilli was studied in pot culture experiment in field, by portioning the field into three, *viz.*, open pollination, self-pollination and stingless bee pollination treatments.

The results of the study are summarized as follows. The work on flight range revealed that 35 % sugar was the most preferred food bait for stingless bee *T. travancorica* which was found on par with 35% honey. Foraging distance of stingless bee was determined to be 378m and an inverse relation between distance and number of bees travelled was noted *i.e.* more numbers of stingless bee was recorded at 100m distance than at 400m distance.

The colony characteristics of stingless bee included brood area inside the hive, colony composition and physical parameters. Observations on brood area inside the hive revealed that the greatest length of brood area observed was 16cm followed by 15cm and least length of brood area was 6cm. Maximum breadth and height of brood area was 12cm followed by 9cm and minimum breadth and height was 4cm. Highest volume of brood area recorded was 1147.5 cm^3 followed by 1020 cm^3 and lowest volume observed was96 cm^3. Volume of pollen and honey pots varied between 21cm^3 to 105 cm^3 and 0.021L to 0.250L respectively.

Only one queen bee was observed in all the 10 hives however, the population of workers varied among all the 10 hives. Maximum population of workers observed was 3255 followed by 2648 and the lowest population of workers observed was 700.

The physical parameters like temperature and relative humidity at the brood area of four stingless bee hives was recorded with the help of data loggers. The minimum and maximum temperature and relative humidity observed in brood area was 22.9°C and 33 °C, 71.7% and 93.3% respectively, while the external air temperature and RH was 24.1 °C and 33.4 °C, 73.1% and 93.3% respectively. The average minimum and maximum temperature and RH from the brood area of four stingless bee hives were 23.32 °C and 32 °C, 78.67% and 98.1% respectively.

The hives made up of four wood types like *T. grandis*, *Artocarpus* sp., *Bridelia* sp. and *Terminalia* sp., were subjected to 40°C inside hot air oven for 3hours to check the best wood types which can control temperature inside the hive. Among all four wood types, *Bridelia* was found to be the best wood type to control temperature inside the hive, which showed an average temperature of 39.56ºC followed by *Terminalia* with 38.2ºC followed by teak with 35.62ºC and jack with 31.86ºC. The time trend followed among wood types to reach 40 ºC was *Bridelia* followed by *Terminalia* followed by teak and jack wood types.

The study on pollination efficacy of stingless bee in chilli was conducted at the instructional farm, College of Agriculture, Vellayani with three treatments and 5 replications. In each replication there were 5 plants and overall, 75 plants were used to conduct the experiment. The plot was divided in to three equal parts for open pollination, self-pollination and stingless bee pollination treatment. The results obtained indicate that, there is significant difference between number of fruits per plant and yield per plant (kg) among all the treatments. Number of fruits per plant and yield per plant was found to be highest in stingless bee pollinated treatment followed by open pollination and self-pollination, with average number of fruits and yield of 80,68 and 59, .081kg, 0.57kg and 0.48kg respectively. Weight

of fruit and percent fruit set was found increased in stingless bee pollinated treatment followed by open and self-pollination, with average weight and percent fruit set recorded 10.08g, 8.48g and 8.41g, 82.74%, 69.69% and 62.14% respectively.

The percent increase in fruit number, weight of the fruit and yield per plant over the control was, 18.1%, 18.8% and 42% respectively.

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FLIGHT RANGE, COLONY CHARACTERISTICS AND POLLINATION EFFICACY OF STINGLESS BEE, *Tetragonula travancorica* IN CHILLI (*Capsicum annuum L.*)

by

BINDU G R

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Abstract of the thesis
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ABSTRACT

The study entitled "Flight range, colony characteristics and pollination efficacy of stingless bee *Tetragonula travancorica* in chilli (*Capsicum annuum L.*)." was conducted at Department of Agricultural Entomology, College of Agriculture, Vellayani, during the year 2018- 2020 with an objective to study the flight range, colony characteristics and pollination efficacy of stingless bee *Tetragonula travancorica* in chilli. To determine the flight range of stingless bees, artificial food bait was standardized and the standardized food bait was used as attractant in order to calculate the foraging distance. Colony composition of ten well maintained stingless bee hives were determined by counting the population of queen and workers and also, the internal nest characteristics like brood area and storage pots were determined. The brood area temperature was recorded from four well maintained stingless bee colonies with the help of data loggers. Stingless bee hives made out of four different wood types were exposed to 40ºC inside hot air oven for 3hrs in order to evaluate their temperature variation. Pollination efficacy of stingless bees in chilli was determined by comparing yield from self- pollination, open pollination and stingless bee pollination respectively.

The study on standardization of food bait for determining flight range revealed that, 35 % sugar concentration was the food bait preferred by stingless bees, which is on par with 35 % honey concentration. The maximum foraging distance of stingless bee was found to be 378m and an inverse relation between distance travelled by the bees and their numbers were observed. Observations on brood area inside the hive revealed that, length, breadth and height of brood area varied between 6cm to 16cm, 4cm to 12cm and 4cm to 12cm respectively. Brood volume varied from 96 cm^3 to 1147.5 cm^3. Volume of pollen pots varied from 21cm^3 to 105 cm^3. Volume of honey pots varied from 0.021L to 0.250L.

The population of queen was similar in all 10 hives *i.e.* one in number and population of workers varied between seven hundred to three thousand two hundred

and fifty-five numbers. The brood area temperature and RH of stingless bee hives varied between 22.9ºC to 33ºC and 71.7 % to 93.3 % respectively. The temperature and relative humidity inside empty hive varied between 24.1ºC to 33.4 ºC and 73.1 % to 98.1 % respectively. It was inferred that the stingless bees have the ability to control humidity and temperature inside the hive.

Bridelia was the best wood type for making stingless bee hives, which control temperature control inside the hive effectively. Bridelia wood exhibited an average temperature control of 39.56ºC followed by Terminalia with 38.2ºC and the lowest temperature control was recorded in jack wood (31.86ºC). The time trend followed by the wood types to reach 40ºC was least in Bridalia followed by Terminalia, Teak and Jack.

Pollination efficiency was maximum in stingless bee pollination followed by open and self-pollination with average fruit set percentage of 82.74%, 69.69% and 62.41% respectively. Number of fruits /plant, yield/ plant, weight of the fruit and percentage fruit set was highest in stingless bee pollination. The percentage increase in yield was 42% over control and percentage increase in fruit number and fruit weight was 18% over the control.