# STUDIES ON THE HOST VARIABILITY AND OVIPOSITIONAL BEHAVIOUR OF LARVAL ECTO-PARASITOID, *Bracon* spp. (HYMENOPTERA : BRACONIDAE) AT RAIPUR, CHHATTISGARH

**Ph.D. (Ag.) Thesis**

**by**

**Sanjay Kumar Ghirtlahre**

**DEPARTMENT OF ENTOMOLOGY**
**COLLEGE OF AGRICULTURE**
**FACULTY OF AGRICULTURE**
**INDIRA GANDHI KRISHI VISHWAVIDYALAYA**
**RAIPUR (Chhattisgarh)**
**2017**

# STUDIES ON THE HOST VARIABILITY AND OVIPOSITIONAL BEHAVIOUR OF LARVAL ECTO-PARASITOID, *Bracon* spp. (HYMENOPTERA : BRACONIDAE) AT RAIPUR, CHHATTISGARH

**Thesis**

**Submitted to**

**Indira Gandhi Krishi Vishwavidyalaya, Raipur**

**by**

**Sanjay Kumar Ghirtlahre**

**IN PARTIAL FULFILMENT OF THE REQUIREMENTS**

**FOR THE DEGREE OF**

**Doctor of Philosophy**

**In**

**Agricultural**

**(Entomology)**

**Roll No. 130114023** **ID.No. 20141520526**

**July, 2017**

# CERTIFICATE – I

This is to certify that the thesis entitled **"Studies on the host variability and ovipositional behaviour of larval ecto-parasitoid, *Bracon* spp. (Hymenoptera : Braconidae) at Raipur, Chhattisgarh"** submitted in partial fulfillment of the requirements for the degree of **Doctor of philosophy in Agriculture** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Sanjay Kumar Ghirtlahre** under my/our guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or has been published/published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

21.7.17

**Chairman**

Date: 21-07-2017

**THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE**

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| Chairman | (Dr. Rajeev Gupta) | ____________ |
| Member | (Dr. Jayalaxmi Ganguli) | ____________ |
| Member | (Dr. Shubha Benerjee) | ____________ |
| Member | (Dr. R.R. Saxena) | ____________ |
| Member | (Head of the Department) | ____________ |

# CERTIFICATE – II

This is to certify that the thesis entitled **"Studies on the host variability and ovipositional behaviour of larval ecto-parasitoid, *Bracon* spp. (Hymenoptera : Braconidae) at Raipur, Chhattisgarh"** submitted by **Sanjay Kumar Ghirtlahre** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur, in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Agriculture** in the Department of **Entomology** has been approved by the external examiner and Student's Advisory Committee after oral examination.

Date: 13.12.2017

Signature External Examiner

(Name: Mayabini Jena. )

**Major Advisor** ____________________

**Head of the Department** ____________________

**Faculty Dean** ____________________

**Approved/Not approved**

**Director of Instructions** ____________________

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**Date:** 20|07|2017

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| Notation | | Description |
|---|---|---|
| % | - | percent |
| $^{o}C$ | - | degree celsius |
| ml | - | milli liters |
| gm | - | grams |
| hrs | - | hours |
| *M* | - | mesor |
| Ø | - | acrophase |
| *A* | - | amplitude |
| $\chi^2$ | - | chi square |
| RH | - | relative humidity |
| Temp | - | temperature |
| ha | - | hectares |
| *i.e* | - | that is |
| p | - | probability |
| @ | - | At the rate |
| Fig | - | figure |
| *Viz;* | - | namely |

## THESIS ABSTRACT

| | | |
|---|---|---|
| a) | Title of the Thesis: | "Studies on the host variability and ovipositional behaviour of larval ecto-parasitoid, *Bracon* spp. (Hymenoptera:Braconidae) at Raipur, Chhattisgarh." |
| b) | Full Name of the Student: | Sanjay Kumar Ghirtlahre |
| c) | Major Subject: | Entomology |
| d) | Name and Address of the Major Advisor: | Dr. Rajeev Gupta, Professor, Department of Entomology, IGKV, Raipur, (C.G.). |
| e) | Degree to be Awarded: | Ph.D., (Ag) Entomology |

Signature of the Student

Signature of Major Advisor

Date: 21.07.2017

21/07/17

Signature of Head of the Department

## ABSTRACT

Biological control has been a valuable tactic in pest management programs and used as a tool used in Integrated Pest Management (IPM) for several field agricultural systems and in protected crops systems. The state has a rich bio-diversity of flora and fauna, hence has a wide scope for exploration of novel bio-control agents. Very little work on the aspect of Biological control of has been done so for in the state, and looking to the above aspects the present study was formed out to determine the species richness of *Bracon* spp. in various crop ecosystems, host range, preference on various stages, and ability of *B. hebetor* to keep down the population of important pests of vegetable crops.

Survey work showed eighteen species of parasitoid wasp *viz., Cotesia flavipes, Elasmus* sp., *Bracon* spp, *Bracon hebetor* Say, *Bracon brevicornis* (Wesmael), *Goniozus* sp. and twelve unidentified species were recorded on various crop ecosystem. Highest number of parasitoids were recorded in paddy, maize and pigeon pea with four species of parasitoids namely *Bracon* sp., *Bracon hebetor* Say, *Cotesia flavipes* Cameron and unknown species. *Bracon brevicornis* and *Goniozus* spp. were recorded for the first time in cabbage and sapota crop ecosystem, respectively. The most dominant parasitoids in decreasing order are *Cotesia flavipes* (32%), *Bracon* sp. (20%), *Bracon hebetor* (7%),*Goniozus* sp.(7%) and *Bracon brevicornis* (2%).

Preference study of *Bracon hebetor* on *Helicoverpa armigera* larvae revealed that shortest life cycle (egg to adult) of *Bracon hebetor* male was recorded in pea reared larvae with 14.81 days and longest developmental period on chick pea reared larvae of 15.80 days. Minimum and maximum developmental days of female was recorded 17.06 and 18.10 days in pea and pigeon pea reared larvae, respectively. The minimum adult longevity of male (4.10 days) was found in chickpea reared larvae whereas the maximum adult longevity of male (5.40 days) was found in okra reared larvae. The minimum adult longevity of female (5.60 days) was found in chickpea reared larvae, maximum adult longevity of female (7.90 days) was found in pigeon pea reared larvae. Longevity of female was longer than male.

Two species of host larvae with second and fourth instar were evaluated for ovipositional preference of *Bracon* spp. Highest fecundity of 37.75 eggs was recorded on *H. armigera* ($4^{th}$ instar) followed by 18.50, 17.50 and 14.0 eggs on *H. armigera* ($2^{nd}$ instar), *S. litura* ($4^{th}$ instar) and *S. litura* ($2^{nd}$ instar), respectively. The lowest egg period (1.13 days) was registered with *S. litura* ($4^{th}$ instar) followed by *S. litura* ($2^{nd}$ instar) and *H. armigera* ($4^{th}$ instar) with 1.50 days for both insects. Maximum time (4.69 days) was required to complete larval duration in case of *H. armigera* ($4^{th}$ instar) in comparison to rest of the host larvae used. Lowest larval duration (3.75 days) was registered in case of *S. litura* ($4^{th}$ instar). Shorter pupal period was exhibited in these three larval hosts over rest of the host larvae used, except *H. armigera* ($4^{th}$ instar) which recorded longest pupal period of 5.63 days. Least duration of life-cycle of female was found in *S. litura* (4th instar) with 17.78 days. Shortest duration of male life-cycle was recorded in *S. litura* (4th instar) with the period of 14.72 days.

All six host species tested were acceptable to the *Bracon hebetor* females for parasitism and oviposition. The highest fecundity (112.80 eggs/female) and lowest fecundity (22.80eggs/female) was observed on rice meal moth, *Corcyra cephalonica* and *Plutella xylostella*, respectively. Shortest pupal period recorded on *P. xylostella* (4.30 days) and the longest on *P. demoleus* (5.42 days). Total developmental periods of adult male from egg to adult was non significantly differed in all the treatments, however, shortest life cycle (18.30 days) of female parasitoid was recorded in *P. xylostella*. The sex ratio was greatest for those reared on *E. macheralis* (1:1.88) and lowest for those reared on *P. xylostella* (1:1.13).

Life table study showed maximum apparent mortality during the egg stage was 30 eggs. Highest mortality rate was registered in larval stage with 52 larvae. The number that survived from 126 eggs to adult emergence was 96 individuals. Females deposited first batch of eggs on 13th day and stopped it after 21st day with lx values being 0.98 and 0.56, respectively. The lx decreased gradually after 14th day of pivotal age due to adult mortality. The females contributed highest number of progeny (mx = 10.0) in the life cycle on the 13th day of pivotal age.

Testing of viability of *B. hebetor* cocoons during storage at different temperatures revealed highest adult emergence (86 ± 2.19 %) was recorded under storage at 12 °C in one week of storage, however emergence of adults were seen up to 6 weeks of storage, but the value decreased.

Different treatments of *Bracon hebetor* were evaluated for their efficacy against *P. xylostella* on cabbage crop by releasing Bracocards. Among the treatments $T_5$ Bracocard (20 cocoons) was found most effective against *P. xylostella* as it recorded lowest larval population of (9.73/plant).

## शोध सारांश

| | | |
|---|---|---|
| अ. | शोध शीर्षक | इल्ली बाह्य परोपजीवी, *ब्रेकान* प्रजाति (हायमेनोप्टेरा : ब्रेकोनिडी) की पोषक भिन्नता एवं अण्डनिक्षेपण व्यवहार का रायपुर, छत्तीसगढ मे अध्ययन |
| ब. | विद्यार्थी का पुरा नाम | संजय कुमार घृतलहरे |
| स. | प्रमुख विषय | कीट विज्ञान शास्त्र |
| द. | प्रमुख सलाहाकार का नाम व पता | डॉ. राजीव गुप्ता<br>प्राध्यापक, कीट विज्ञान विभाग<br>कृषि महाविद्यालय इ.गाँ.कृ.वि., रायपुर (छ.ग.) |
| इ. | सम्मानित किये जाने वाली उपाधि | पी एच.डी. कृषि कीट विज्ञान शास्त्र |

विद्यार्थी के हस्ताक्षर

प्रमुख सलाहकार के हस्ताक्षर

21/07/17

दिनाँकः 21. 7. 2017

विभागाध्यक्ष के हस्ताक्षर

## सारांश


जैविक कीट नियंत्रण कीट प्रबंधन कार्यक्रम के लिए महत्वपूर्ण रणनीति होता है। यह अनेक कृषि प्रक्षेत्र तथा संरक्षित फसल पद्धति मे समन्वित कीट प्रबंधन के हथियार के रूप मे उपयोग होता है। छत्तीसगढ राज्य जो वनस्पति एवं प्राणिजगत से समृद्ध है, इसलिए यहां जैव नियंत्रण कारक के अनुसंधान के लिए वृहत क्षेत्र है। इस राज्य मे जैविक कीट नियंत्रण से संबंधित अत्यंत सीमित कार्य हुआ है। उपरोक्त जानकारी को देखते हुए वर्तमान अध्ययन विभिन्न फसल परितंत्र मे *ब्रेकान* प्रजाति संमृद्धि, पोषक वर्ग, विभिन्न वर्ग मे प्राथमिकता एवं हानिकारक कीट को नियंत्रित करने की क्षमता का मुल्यांकन करने के लिए वर्तमान अध्ययन किया गया। विभिन्न फसल परितंत्र मे सर्वेक्षण के दौरान अठारह परोपजीवी बर्र जैसे *कोटेसिया फ्लेविपस, इलासमस* प्रजाति, *ब्रेकान* प्रजाति, *ब्रेकान हेबेटर, ब्रेकान ब्रेविकोर्निस, गोनियोजस* प्रजाति एवं बारह अज्ञात प्रजाति अभिलिखीत किया गया। धान, मक्का एवं अरहर फसल परितंत्र मे अधिकतम संख्या (चार) मे परोपजीवी कमशः *ब्रेकान* प्रजाति, *ब्रेकान हेबेटर, कोटेसिया फ्लेविपस* एवं अज्ञात परोपजीवी अभिलिखीत किया गया। *ब्रेकान ब्रेविकोर्निस, गोनियोजस* प्रजाति प्रथम समय के लिए कमशः पत्तागाभी एवं चीकू परितंत्र मे अभिलिखीत किया गया। सर्वाधिक प्रभुत्व *कोटेसिया फ्लेविपस* (32 प्रतिशत), *ब्रेकान* प्रजाति (20 प्रतिशत), *ब्रेकान हेबेटर* (7 प्रतिशत), *गोनियोजस* प्रजाति (7 प्रतिशत), एवं *ब्रेकान ब्रेविकोर्निस,* (2 प्रतिशत) पाया गया।

*ब्रेकान हेबेटर* की प्राथमिकता अध्ययन से ज्ञात होता है कि नर परोपजीवी का जीवन चक अल्प समय (14.81 दिन) का एवं अधिकतम 15.82 दिनो का जीवन चक कमशः मटर एवं चना मे पले *हेलिकावर्पा आर्मिजेरा* की इल्ली मे पाया गया। मादा परोपजीवी का जीवन चक अल्प समय (17.06 दिन) का एवं अधिकतम समय (18.10 दिन) का जीवन चक मटर एवं चना मे पले *हेलिकावर्पा आर्मिजेरा* की इल्ली मे

पाया गया। वयस्क नर का न्यूनतम आयु 4.10 दिनो का चना मे पले *हेलिकावर्पा आर्मिजेरा* की इल्ली मे एवं अधिकतम आयु 5.40 दिन भिण्डी मे पले *हेलिकावर्पा आर्मिजेरा* की इल्ली मे पाया गया। मादा वयस्क की न्यूनतम आयु 5.60 दिन एवं अधिकतम आयु 7.90 दिन क्रमशः चना एवं मटर मे पले *हे. आर्मिजेरा* की इल्ली मे पाया गया। नर वयस्क की तुलना मे मादा वयस्क अधिकतम दिनो तक जीवित रहती है।

*ब्रेकान हेबेटर* की अण्डनिक्षेपण प्राथमिकता का मुल्यांकन *हे. आर्मीजेरा* एवं *स्पोडोप्टेरा लिटूरा* की द्वितीय एवं चतूर्थ इन्सटार इल्ली मे देखा गया। जिसमे अधितम 37.75 अण्डे *हे. आर्मीजेरा* (चतूर्थ इन्सटार) मे इसके पश्चात 18.50, 17.50 एवं 14.0 अण्डे क्रमशः *हे. आर्मीजेरा* (द्वितीय इन्सटार), *स्पोडोप्टेरा लिटूरा* (चतूर्थ इन्सटार) एवं *स्पोडोप्टेरा ल*िटूरा (द्वितीय इन्सटार) मे पाया गया। न्यूनतम 1.13 दिनो के लिए अण्डा अवस्था *स्पो. लिटूरा* (चतूर्थ इन्सटार) मे पाया गया। *ब्रे. हेबेटर* की इल्ली अवस्था अधिकतम 4.69 दिनो के लिए एवं न्यूनतम अवधि 3.75 दिन क्रमशः *हे. आर्मीजेरा* (चतूर्थ इन्सटार) एवं *स्पो. लिटूरा* (चतूर्थ इन्सटार) मे पाया गया। कोकून अवस्था सभी पोषक इन्सटार की तुलना मे अधिकतम 5.63 दिन *हे. आर्मीजेरा* (चतूर्थ इन्सटार) मे पाया गया। नर परोपजीवी का जीवन चक्र अल्प समय 14.72 दिन एवं मादा परोपजीवी का जीवन चक्र अल्प समय 17.78 दिन के लिए *स्पो. लिटूरा* (चतूर्थ इन्सटार) की इल्ली मे पाया गया।

*ब्रे. हेबेटर* के जीवन चक्र अध्ययन मे मूल्यांकन किये गये सभी छः पोषक इल्ली मे 80 अण्डा/मादा) एवं न्यूनतम अण्डो की संख्या (22.80 अण्डा/मादा) क्रमशः *कोरसायरा सिफेलोनिका* एवं *प्लूटेला जाइलोस्टेला* की इल्ली मे पाया गया। न्यूनतम एवं अधिकतम कोकून अवस्था क्रमशः 4.30 एवं 5.42 दिन *प्लू. जाइलोस्टेला* एवं *पेपिलियो डेमोलियस* मे देखा गया। नर परोपजीवी का जीवन चक्र सभी पोषक इल्लियो मे एक समान था जबकि मादा *ब्रेकान* का न्यूनतम जीवन चक्र 18.30 दिन *प्लू. जाइलोस्टेला* मे पाया गया। अधिकतम लिंगानुपात (1:1.88) *यूटेक्टोना मेचीरेलिस* एवं न्यूनतम लिंगानुपात (1:1.13) *प्लू. जाइलोस्टेला* मे देखा गया।

*ब्रे. हेबेटर* की जीवन सूची अध्ययन से ज्ञात होता है कि अधिकतम मृत्यू दर (52 इल्ली) *ब्रेकान* की इल्ली अवस्था मे पाया गया। प्रारंभिक 126 अण्डो मे से केवल 96 इल्ली ही बन पाये। 13वे दिन मे lx मान 0.98 के साथ प्रथम अण्ड निक्षेपण प्राप्त हुआ अपितु 21वे दिन मे अण्डनिक्षेपण lx मान 0.56 के साथ स्थिर हो गया। मृत्यू दर के कारण lx का मान क्रमशः घटते हुए पाया गया। मादा कीट द्वारा अधिकतम संख्या मे संतति mx मान 10.0 के साथ जीवन के 13वे दिन पाया गया।

भण्डारण के दौरान *ब्रेकान* की कोकून का जीवन क्षमता विभिन्न तापमान $27^0C$ , $12^0C$ , $9^0C$ , एवं $4^0C$ मे मूल्यांकन किया गया। भण्डारण अवस्था के दौरान अधिकतम वयस्क का आर्विभाव $86\pm2.19$ प्रतिशत $12^0C$ तापमान मे एक सप्ताह भण्डारण मे पाया गया जबकि वयस्क का आर्विभाव घटते क्रम मे छः सप्ताह तक अवलोकित किया गया।

पत्तागोभी मे हीरक पृष्ठ शलभ, *प्लूटेला जाइलोस्टेला* के प्रबंधन के लिए *ब्रेकान हेबेटर* की क्षमता का मूल्यांकन किया गया। समस्त ब्रेकाकार्ड मे से ब्रेकाकार्ड (20 कोकून) न्यूनतम इल्ली (9.73/पौधा) के साथ हीरक पृष्ठ शलभ के लिए अधिक प्रभावशाली पाया गया।

## CHAPTER- I

# INTRODUCTION

Biological control has been a valuable tactic in pest management programs around the world for many years. Biological control is a natural phenomenon of plant and animal regulation by their natural enemies. Biological control is a tool used in Integrated Pest Management (IPM) for several field agricultural systems and in protected crops systems. This technology is economically viable, of low environmental impact, and does not present risks of environmental contamination, human health nor for domestic animals (Orr, 2009). In the case of pest management, the major natural enemies are other insects, known as entomophagous, or microorganisms as entomopathogens. The entomophagous group is represented by predators and parasitoids. Most of the natural enemies belong to the order Hymenoptera.

Hymenopterans are one of the four megadiverse orders at world level. Females typically have a special ovipositor for inserting eggs into hosts or otherwise accessible places. The ovipositor is often modified into a stinger. Braconidae is the second largest family of Hymenoptera, comprising about 4,000 species, which are distributed throughout the world in several different habitats (Sharkey, 1993). They are considered key-species for maintenance of balance of insect communities.

The braconid (Hymenoptera:Braconidae) is a cosmopolitan, gregarious, idiobiont arrhenotokous, ecto-parasitoid which lays large, yolky eggs on the integument of its host and parasitizes the larvae of Lepidoptera, Coleoptera and Diptera. Braconid is an important biological control agent for several insect pests (Heimpel *et al*., 1997; Darwish *et al*., 2003). Braconids have been widely used in various studies related to host-parasitoid interactions due to its high reproductive rate, short generation time, and considerable range of host species (Yu *et al*., 2002).

*Bracon hebetor* is considered one of the best potential biological control agents for stored-product insects in the family Pyralidae (Brower *et al.*, 1996). *B. hebetor* females first paralyze their host, which are typically last-stage larvae in a "wandering" phase, by stinging them, injecting a paralytic venom, and ovipositing variable numbers of eggs on or near the surface of paralyzed host. Hymenopteran insects incapacitate their prey by a diversity of neurotoxins, resulting in block of synaptic transmission in CNS or neuromuscular junctions, or affecting voltage dependent phenomena on nerve and muscle fibres (Piek, 1990).

*Bracon hebetor* Say (Hymenoptera: Braconidae) is an ecto-parasitoid that attacks the $4^{th}$ -and $5^{th}$ stage of pyralid moth larvae, including the greater wax moth (GWM) *Galleria mellonella* (L.) (Lepidoptera: Pyralidae) (Awadallah *et al*., 1985), *Plodia interpunctella* (Hübner) (Milonas, 2005), *Corcyra cephalonica* (Stainton) (Krombein *et al.*, 1979), *Ephestia kuehniella* Zeller (Darwish *et al*., 2003) and *Helicoverpa armigera* Hubner, *Heliothis virescens* (F.) (Attaran, 1996), that infest field crops as well as stored-products (Benson, 1974). The parasitoid is considered as a potential biological control agent of the lepidopteran stored product pests (Brower *et al*., 1996) and also some of field insect pests.

*Bracon hebetor*, is an ectoparasitoid of the larvae of many pyralid pest-species, that attack stored grains (Brower *et al.*,1990). The parasitoid is considered to have a high potential for the biological control, of many other lepidopterous pests, of various crops, because it is highly aggressive (Keever *et al.*, 1985). It occurs, naturally, throughout the world. There is a growing evidence that *B. hebetor* can also be an important bio-control agent of *Helicoverpa armigera* (Nikam and Pawar, 1993). The biology of *B. hebetor,* has been intensively studied because of it's suitability as a model organism, which is easy to rear in the laboratory and has also a great potential for being used as a biological control agent of many lepidopterous pests.

According to Heimpel *et al.* (1997), the wasp species *B. hebetor* can successfully attack larvae in the family Noctuidae in the field. A host value to the reproductive fittness of a parasitoid mainly depends on the number and quality of the progeny from that host. Thus, physiological suitability of the host is absolutely necessary for the successful development of parasitoid progeny (Wiedenmann and Smith 1997). Similarly, a parasitoid's fitness also depends on its ability to locate and recognize its host in a complex environment and to produce a high or optimum number of viable and high-quality progeny from that host.

Biological control is both economically and ecologically feasible for farmers to use, in addition, helping to reduce the negative impacts of intensive chemical based pest management on the environment. Biological control methods have been highlighted by researchers as a promising alternative to chemical pesticide application for the control of economically important pests.

Chhattisgarh state was formed on 1$^{st}$ November 2000, and since then it is marching ahead in all fields including agriculture. Multiple cropping and organic mode of forming are its recent developments. Biological control is the need of the hour towards a eco-friendly management of insect pests to sustain a healthy and pollution free environment and to save the non target species. The state has a rich bio-diversity of flora and fauna, hence has a wide scope for exploration of novel bio-control agents. Very little work on the aspect of Biological control of has been done so for in the state, and looking to the above aspects the present study was formed out to determine the species richness of *Bracon* spp. in various crop ecosystems, host range, preference on various stages, and ability of *B. hebetor* to keep down the population of important pests of vegetable crops, entitled **"Studies on the host variability and ovipositional behaviour of larval ecto-parasitoid, *Bracon* spp. (Hymenoptera : Braconidae) at Raipur, Chhattisgarh"** with the following objectives.

1. To record the naturally available species of *Bracon* on few cereals, legumes, vegetables and fruits at Raipur, Chhattisgarh ecosystem.
2. Preference of *Bracon* spp. on *Helicoverpa armigera* Hub. feeding on different hosts.

3. To study the ovipositional preference of *Bracon* spp. on second and fourth instars of host insects.

**Apart from the above objectives studies on the following aspects were also under taken:**

4. To study the biology of *Bracon hebetor* Say (Hymenoptera : Braconidae) on various lepidopteran larvae under laboratory conditions.
5. To construct the life table of *Bracon hebetor* on *Corcyra cephalonica* Stainton (Lepidoptera : Pyralidae).
6. To study the viability of *Bracon hebetor* (Say) cocoons during storage as Bracocards.
7. To study the management of diamonback moth, *Plutella xylostella* L. on cabbage crop by release of *Bracon hebetor* Say under field conditions.

# CHAPTER- II
# REVIEW OF LITERATURE

This chapter deals with the brief account of research work done on the related aspects by various workers from the state, country and abroad. The literature pertaining to the present investigation entitled **"Studies on the host variability and ovipositional behaviour of larval ecto-parasitoid, *Bracon* spp.(Hymenoptera : Braconidae) at Raipur, Chhattisgarh"** were collected and grouped under the following headings.

**2.1** To record the naturally available species of *Bracon* on few cereals, legumes, vegetables and fruits at Raipur, Chhattisgarh ecosystem.

**2.2** Preference of *Bracon* spp. on *Helicoverpa armigera* Hub. feeding on different hosts.

**2.3** To study the ovipositional preference of *Bracon* spp. on second and fourth instars of host insects.

**Apart from the above objectives studies on the following aspects were also under taken:**

**2.4** To study the biology of *Bracon hebetor* Say (Hymenoptera : Braconidae) on various lepidopteran larvae under laboratory conditions.

**2.5** To construct the life table of *Bracon hebetor* on *Corcyra cephalonica* Stainton (Lepidoptera : Pyralidae).

**2.6** To study the viability of *Bracon hebetor* (Say) cocoons during storage as Bracocards.

**2.7** To study the management of diamonback moth, *Plutella xylostella* L. on cabbage crop by release of *Bracon hebetor*Say under field conditions.

## 2.1 To record the naturally available species of *Bracon* on few cereals, legumes, vegetables and fruits at Raipur, Chhattisgarh ecosystem.

Saparmamedova (1988) reported natural enemies of the plum moth, *Grapholitha funebrana* Tr. (Lepidoptera, Tortricidae) in the Prikopetdag zone. Investigations in the Kopetdag foothills of Turkmenia, USSR, in 1984-86 and showed that *Pimpla spuria*, *Mesostenus transfuga*, *Venturia canescens*, *Ascogaster* *quadridentata*, *Bracon hebetor*, *Brachymeria rugulosa*, *Hockeria micula*, *Dibrachys cavus* and *Mastrus* sp. were parasitoids of *Grapholita funebrana* (*Cydia funebrana*), *A. quadridentata* being the most active.

Borah and Saharia (1989) recorded *Aulosaphes* sp. as the dominant parasitoid of *Cnaphalocrocis medinalis*, followed by *Bracon* sp. The rate of parasitization of *C. medinalis* by *Aulosaphes* sp. and *Bracon* sp. increased with an increase in pest numbers, and peaked either coincidentally or after the peak incidence of the pyralid. Relative humidity was the most important environmental factor responsible for triggering the appearance of, and regulating parasitoid density.

Gubbaiah, and Revanna (1989) recorded larval parasitoids (*Bracon brevicornis* and *Perisierola nephantidis* (*Goniozus nephantidis*) and pupal parasitoids (*Brachymeria* spp.) occurred naturally on coconut black headed caterpillar, *Opisina arenosella* and exerted some control on the pest population.

Maini and Burgio (1990) recorded parasitoids of *Ostrinia nubilalis* (Hb.) in Emilia Romagna, Italy. Tachinid *Lydella thompsoni*, the ichneumonids *Sinophorus turionus* and *Eriborus terebrans* (*Diadegma terebrans*), braconids, *Chelonus annulipes* and *Habrobracon hebetor* (*Bracon hebetor*) and the trichogrammatid, *Trichogramma maidis* were recorded as major natural enemies of *O. nubilalis.*

Stam and Elmosa (1990) recorded *Earias insulana* and *Helicoverpa armigera* as the most damaging pest of cotton in the Syrian agro-ecosystem. Egg and larval populations of *E. insulana* and *H. armigera* were parasitized by *Trichogramma* spp. and the braconid, *Habrobracon brevicornis* (*B. brevicornis*), respectively.

Yasarakinci and Kornosor (1990) reported that $1^{st}$- to $4^{th}$-instar larvae were parasitized by *Diadegma* sp. and *Hyposoter didymator* at rates of 19.7 and 6.2% during 1988 and 1989, resp. $5^{th}$ and $6^{th}$ instar larvae were parasitized by *Habrobracon brevicornis* (*Bracon brevicornis*) at 47.6 and 38.8% parasitization.

Abbas and El Deeb (1993) recorded natural parasitization of *Pectinophora gossypiella* was parasitized by *B. brevicornis*, *Exeristes roborator* and *Apanteles*sp and *Spodoptera littoralis* by *Chelonus inanitus*. *Microplitis rufiventris*.

Gaston (1993) reported spatial patterns in the description and richness of the Hymenoptera. The type localities of 8000 species of Hymenoptera described during 1984-89 had a highly skewed distribution, with the largest number of species being described from the former USSR, followed by the USA, with these 2 areas accounting for >20% of descriptions. Of nations from which >100 species were described, only 6 could be regarded as truly tropical.

Reymonet *et al*. (1993) conducted a survey of the parasitoids of the European sunflower moth *Homoeosoma nebulella* (Lep.: Pyralidae) in the Palearctic region. The parasitoids of this pyralid are little known. *Diadegma* spp., *Bracon trucidator* (*B. minutator*), *Chelonus oraculator*, *Habrobracon hebetor* (*Bracon hebetor*), *Chelonus fissuralis* and *Scambus* spp. were recorded.

Sharma (1993) recorded new braconid parasitoids on *Eublemma amabilis,* Moore a pest of *Kerria lacca* (Kerr). The braconids *Euremeros namkumense* sp. nov. and *E. tumespiraculum* were recorded as parasitoids of *Eublemma amabilis* (which preys on *Kerria lacca*) in India for the first time. Braconidae, *Bracon greeni*, *B. hebetor, Aphrastobracon flavipennis, Apanteles fakhrulhajiae and A. teacherdiae* are recorded as parasitoids of another predator of *K. lacca, Holcocera pulverea* (*Pseudohypatopa pulverea*).

Noori (1994) investigated parasitism of *Heliothis* by *Habrobracon hebetor* (*B.hebetor*) in Iran. Activity of the parasitoid began in early June in chickpea fields and lasted until mid-September in maize and tomato fields. Parasitism rates increased as temperatures increased, and in 1986 rose from 24% in mid-June to 95% in early July. Parasitism began about one week earlier in chickpea fields sown early than in those sown later. In late-sown fields all the larvae were parasitized in the $1^{st}$ half of July, but in early-sown fields a small proportion of the larvae remained unparasitized. By rearing the braconid in the laboratory, these obstacles could be overcome and releases should begin at least one week before the peak population of the pest.

Pillai and Nair (1995) reported superiority of the solitary parasitoids over gregarious species in the biological suppression of the coconut caterpillar, *Opisina arenosella* Walker. About 40 species of parasitoids were recorded in association with the coconut caterpillar, *O. arenosella,* in India and Sri Lanka. Apart from the dominant tachinid parasitoid, *Stomatomyia bezziana*, all other species are prevalent in India. Among these, only seven species of parasitoids (*B. hebetor*, *B. brevicornis* and *Goniozus nephantidis* attacking the larvae, *Elasmus nephantidis* (attacking prepupae) and *Tetrastichus israeli, Trichospilus pupivorus* and *T. diatraeae*) are gregarious.

Kfir (1997) identified twenty one species of parasitoids of *Plutella xylostella* on cabbage field from in South Africa *viz.* the egg-larval parasitoids *Chelonus curvimaculatus* and *Chelonus* sp. (Braconidae); the larval parasitoids *Cotesia plutellae*, *Habrobracon brevicornis* (*Bracon brevicornis*) (Braconidae) and *Peribaea* sp. (Tachinidae); the larval-pupal parasitoids *Diadegma* sp., *Itoplectis* sp. (Ichneumonidae) and *Oomyzussokolowskiio* (Eulophidae); the pupal parasitoids *Brachymeria* sp., *Hockeria* sp. (Chalcididae), *Diadromus collaris* (Ichneumonidae) and *Tetrastichus howardi* (Eulophidae); and the hyperparasitoids *Aphanogmus fijiensis* (Ceraphronidae), *Brachymeria* sp., *Hockeria* sp., *Proconura* sp. (Chalcididae), *Mesochorus* sp. (Ichneumonidae), *Pteromalus* sp. (Pteromalidae), *Eurytoma* sp. (Eurytomidae) and *Tetrastichus* sp. (Eulophidae).

Sanchez-Garcia *et al.*(1998) collected braconids from different localities of Guanajuato, Mexico, from 1995 to 1996. A list of 61 genera in 31 tribes and 19 subfamilies of braconids were obtained. The most abundant genera were *Aphidius*, *Opius* and *Apanteles*. Genera with the largest number of species were *Bracon* and *Opius*. From these genera, 45 were new records for Guanajuato and one was a new record for Mexico was *Eubazus*. species from the genera *Aphidius, Diaeretiella, Lysiphlebus, Praon, Trioxys, Habrobracon* (*Bracon*), *Bracon, Digonogastra, Chelonus, Meteorus, Apanteles, Cotesia, Opius, Orgilus and Aleiodes* were found to be parasitic on different pest species of economic importance.

Diaconu and Lozan (2000) recorded ectoparasitoid braconids of certain species of leaf rollers (Lepidoptera: Tortricidae) of fruit trees. Leaf roller larvae collected from species of *Malus*, *Pyrus*, *Prunus* and *Cerasus* in several localities of Romania, between 1992 and 1998, five species of braconids were identified as larval ectoparasitoids (*B. hebetor, B. picticornis, B. variator, B. variegator* and *Oncophanes laevigatus*), belonging to the Braconinae and Doryctinae. Sixteen host-parasitoid relationships have been recorded, most of them new to science. The role played by these parasitoids in the limitation of leaf-roller populations on fruit trees is generally minor, the parasitization rate being below 1%. Also, some cases of double parasitism of *B. picticornis* and *O. laevigatus* by certain species of Eulophidae (*Colpoclypeus florus*, *Sympiesis acalle*) or Ichneumonidae (*Scambus planatus*) was mentioned.

Voloshenko and Khachumov (2000) carried studies on *Habrobracon hebetor* (*B. hebetor*), its host plants, role as a biological control agent, rearing techniques, and storage at Russia. During spring and summer of 1996-99, special cassettes with larvae of the Mediterranean flour moth (*Ephestia kuenhiella*) were used to catch *H. hebetor* on maize, tomatoes, apples, quince, raspberries, Acacia spp. and rose hips. Larvae of *E. kuehniella* are also used to rear *H. hebetor* in the laboratory. In 1999, laboratory-reared *H. hebetor* were successfully used for the control of *Helicoverpa armigera* in tomato fields.

Ebenebe *et al*. (2001) conducted field surveys during 1995 and 1996 seasons in Lesotho, during entomological surveys predatory ants and parasitoids of the stem borers *Busseola fusca* and *Chilo partellus* were collected from the field of maize and sorghum. Parasitoids and *Dorylus helvolus* were sampled at regular intervals in field trials. Two braconid species, *B. sesamiae* and *Cotesia sesamiae*, were found to parasitize both *B. fusca* and *Chilo partellus* larvae in maize and sorghum. Two other species, *Euvipio* (*Stenobracon*) sp. and *B. brevicornis*, were reared from *B. fusca* larvae. *B. sesamiae* was the most abundant and widespread of the four larval parasitoids. The activities of natural enemies increased only towards the end of the growing season.

Carlos and Angelica (2002) identified the genera of Braconidae (Hymenoptera) collected in a remnant area of native forest in Itumbiara County, State of Minas Gerais, Brazil, using Malaise traps. After 24 sample collections, a total of 49 specimens from 19 different genera and 10 subfamilies were obtained. The most frequent genus was *Chelomus* with 34.7% frequency. March and June were the months of highest occurrence of Braconidae.

Rongbin *et al*. (2002) recorded natural enemies of tobacco storage pests in Fujian Province. The main natural enemies *viz.,Habrobraconbrevicornis*

(*B.brevicornis*) and *Litomastix* sp. Furthermore, *B. xyletini* was reported for the first time in China.

Narayanamma (2003) recorded natural enemies and per cent parasitisation of citrus butterfly, *Papilio demoleus* on sweet orange and acid lime. Three braconid parasitoids, *viz*., *Apanteles* sp., *A. papilionis* (*Distatrix papilionis*) and *B. hebetor* were found to be associated with larval population of the butterfly. The highest rate of parasitization was observed during November to January on sweet orange and from second fortnight of November to January on acid lime. Peak periods of parasitization synchronised with the peak periods of pest activity. Correlation co-efficient values were determined among weather factors and percentage parasitization. Negative and significant correlation of these parameters was observed between the parasitization with temperatures (maximum and minimum), while positive and significant correlation was observed with relative humidity and a positive and non-significant correlation was observed with rainfall on both hosts.

Sujatha and Singh (2003) reported occurrence of parasitoids of *Opisina arenosella* from September 1996 to August 1997 in pest-infested coconut plantation in Karnataka, India. *Apanteles taragamae, B. brevicornis* and *Meteoridea hutsoni* were the most effective parasitoids during the rainy, summer and winter seasons, respectively. The mean maximum temperature and sunshine hours were negatively correlated with parasitism of *A. taragamae* on adult palms. Significant positive correlation was observed between its parasitism and pest population only on adult palms. However, the mean maximum temperature and sunshine hours showed significant positive correlation with parasitism of *B. brevicornis* on adult palms. The minimum temperature and rainfall showed significant negative correlation with parasitism by *M. hutsoni*. The significant positive relationship of *M. hutsoni* and *B. brevicornis* with sunshine hours on adult palms revealed the favourable influence of light with the population build up at greater height. The significant positive correlation between parasitism by *M. hutsoni* and pupal and larval populations of *O. arenosella* revealed a density-dependent relationship with pest population.

Sathe (2004) identified thirty seven species of braconid (Braconidae) parasitoids in southern Maharashtra, India. *Cotesia, Apanteles, Dolichogenidea, Microplitis, Bracon, Chilenus, Glyptapanteles, Meteorus* and *Rhigoplitis* species were the most common in this region. *Cotesia flavipes*, *Cotesia chilonis* and *Cotesia sesamiae* parasitized 22, 5 and 7% of the larvae of *Chilo partellus*, respectively. *Cotesia ruficrus* attacked 8% of the larvae of *Helicoverpa armigera*. *Cotesia glomerata* parasitized 4% of the larvae of *Pieris brassicae*, whereas *Cotesia orientalis* and *Cotesia diurnii* parasitized 30 and 11% of *Exelastis atomosa* larvae, respectively. *Meteorus dichomeridis* and *Meteorus spilosomae* parasitized the larvae of *Spilosoma obliqua* (*Spilarctia obliqua*) (34 and 12%). Parasitism by *Apanteles* spp. ranged from 5 to 34%. *B. brevicornis* parasitized the larvae of *Earias fabia* (*E. vittella*) (18%) and *Earias insulana* (7.5%). *Dolichogenidea mythimna* was an effective parasitoid of *Mythimna separata* (36%). *G. malshri* parasitized 13% of *Plutella xylostella* larvae.

Mojeni *et al*. (2005) recorded egg, larval and pupal parasitoids of bollworm, *Helicoverpa armigera* (Hub.) *viz.*, *Trichogramma brassicae*, *T. embryophagum*, *Habrobracon hebetor* (*B. hebetor*), *Barylypa amabilis*, *B. pallida* and *Ichneumon sarcitorius*.

Sertkaya *et al*. (2005) investigated the parasitoid species attacking larvae and pupae of *Sesamia nonagrioides* that overwinters in maize stubble under field conditions in Balcal (Adana, Turkey). Overwintering larvae and pupae were sampled. Five hymenopteran (Braconidae and Ichneumonidae) parasitoid species were found associated with larvae and pupae of *S. nonagrioides*. The braconid larval parasitoids, *Cotesia ruficrus*, *Habrobracon hebetor* (*B. hebetor*) were recorded as natural enemies of overwintering generation of *S. nonagrioides*.

Ahemaiti *et al*. (2006) recorded frequent species of Braconid in cotton field in China. The most frequent dominant species of larval parasitoid were *B. hebetor*, *Microplitis mediator*, *Macrocentrus collaris*, *Dinocampus coccinellae* and *Aphidius evenae*. *Habrobracon hebetor* infesting *Helicoverpa armigera* in the field.

Bayram *et al*. (2007) investigated factors affecting overwintering mortality in the Mediterranean corn stalk borer, *Sesamia nonagrioides* Lefebvre

(Lepidoptera: Noctuidae), under field conditions in the Turkey. During two consecutive years larvae and pupae were sampled from December to April in maize plots sown on three different dates. Field-collected larvae and pupae were reared and the emerged parasitoids were recorded. An effect of sowing date on total number of *S. nonagrioides* was found with reduced populations in the early sown plots. *Habrobracon hebetor* (Say) (Hymenoptera: Braconidae) caused 1.1% parasitism and was found only in the first year of the study.

Jayanthi and Verghese (2007) recorded parasitoids on sapota seed borer, *Trymalitis margarias* Meyrick in Karnataka, India Two types of parasitoids were observed parasitizing sapota seed borer. They were identified as *Bracon* sp. and *Eurytoma braconidis*. In all cultivars, parasitism increased as fruit size increased and reached peak during fruit maturity, which usually coincided with host larval sapota seed borer, *T. margarias* Meyrick exit. The parasitoids allowed the host larvae to mature and tunnel the exit gallery from the seed through the pulp up to fruit epidermis. Just before host larval emergence, the parasitoids emerged from the host larvae. Natural parasitization by *Bracon* sp. among the cultivars and sizes varied from 12.50-57.14%.

Politz, *et al*. (2007) found that occurrence of *B. brevicornis* as a parasitoid of European corn borer (*Ostrinia nubilalis*) occurs in Saxony (Germany) since 1995.

Papp (2008) described sixteen valid *Bracon* species by SZEPLIGETI from the Western Palaearctic Region *viz*., *B. osculator* Nees, *B. abbreviator* Nees, *B. minutator* (Fabricius), *Bracon novu,s B. maculifer, Bracon rugulosus, B. neglectus, B. spurnensis, Bracon sabulosus, Glabriolum turkestanum, B. subrugosus* and *B. trypetanus* Fahringer.

Yasodha and Natarajan (2009) reported twelve parasitoids on *Leucinodes orbonalis* belonging to two super families *viz*., Ichneumonoidea and Chalcidoidea emerged from field collected *L. orbonalis* larvae during survey. The parasitoids identified were *viz., Trathala flavoorbitalis* Cameroon, *Phaneratoma* sp. *Chelonus* sp., *Vaepellinae* sp. *B. hebetor* Say, *Antrocephalus mitys* Walker, *Brachymeria lasus* Walker, *Spalangia irregularis* Walker, *Spalangia endius* Walker, *Endius* sp.

*Spalangia* sp. and *Trichogramma* sp. were found to parasitize eggs of *L. orbonalis*.

PerezUrbina *et al.* (2011) reported 26 subfamilies, 261 genera and 355 species from Mexico. In the State of Tamaulipas, 25 subfamilies, 130 genera and 156 species have been registered. During 2003, braconids were collected in one Malaise trap, placed in the spiny shrub at "Canon del Novillo", Victoria, Tamaulipas, obtaining representatives of 16 subfamilies, 39 genera and 48 species. Taxa best represented were the subfamilies Microgastrinae and Agathidinae, the genus *Bracon* and the species *Alabagrus nigritulus* Szepligeti.

Sharma and Srivastava (2011) recorded two parasitoids as associated natural enemies on leaf webber larvae, *Pempelia morosalis* in eastern Uttar Pradesh of India i.e., *Bracon hebetor* (Say) and *Tachinid* sp. Both parasitoids successfully completed their biology on $4^{th}$ instar larvae of *P. morosalis*. On providing two leaf webber larvae for a pair of *B. hebetor*, a total of 36 to 49 individual parasitoids were obtained, whereas in case of *Tachinid* sp., a total of 21 to 37 individual parasitoids were obtained in research study.

Borkar and Sarode (2013) observed parasitization of *Helicoverpa armigera* (Hubner) in non *Bt*-cotton. The larvae of *H. armigera* collected from field were parasitized by *Eriborus* spp., *Bracon* spp., *Apanteles* spp., *C. Chlorideae* among them, *Eriborus* spp. were found effective parasitoid.

Lotfalizadeh and Hosseini (2013) conducted survey of storage pests parasitoids (Hymenoptera) in Iran. Agricultural stored products threatened by several storage insect pests with about 6-10% reduction in Iran. Storage pests were found to be attacked by several species of natural enemies especially Hymenopterous parasitoids. Ten parasitic wasps belonging to three superfamilies, Bethyloidea (two species on small beetles), Chalcidoidea (six species on coleopterous pests) and Ichneumonoidea (two species on lepidopterous pests) were listed from Iranian fauna. These parasitoids are as follow: Two bethylids species *Cephalonomia tarsalis* (Ashmead) and *Laelius anthrenivorus* Trani; two braconids *Bracon hebetor* Say and *B. brevicornis* (Wesmael); six pteromalids species *Anisopteromalus calandrae* (Howard), *Dinarmus vagabundus* (Timberlake), *Lariophagus distinguendus* (Forster), *Pteromalus* sp., *Tbeocolax elegans*

(Westwood), *T. formiciformis* Westwood. Within these parasitoids, *A. calandrae* is a well known cosmopolitan parasitoid of Anobiidae and Bruchidae (Coleoptera).

Moolman *et al*. (2013) recorded *Bracon* sp. (Hymenoptera: Braconidae) and *Cotesia sesamiae* (Hymenoptera: Braconidae) in South Africa and Mozambique, 20 species of parasitoids were recovered from 17 stem borer species collected on 16 wild host plant species. From Mozambique, 14 parasitoid species were recorded from 16 stem borer species collected on 14 wild host plants. The highest diversity of parasitoids was recorded on stem borers that attacked the host plants *Phragmites australis* (7 spp.) and *Panicum maximum* (6 spp.).

Ghirtlahre (2014) recorded Braconids on the larvae of sapota leaf webber, *Nephopteryx eugraphella* Ragonot and marble moth, *Celypha woodiana* Barrett at the Horticulture Instructional Farm, TCB College of Agriculture and Research Station Bilaspur, a constituent College of Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh) India.

Moghanlou *et al*. (2014) recorded *Habrobracon hebetor* (Say) as a potential natural enemy of *Ostrinia nubilalis* (Hubner) on four corn hybrids in Moghan region.

Afiunizadeh and Karimzadeh (2015) reported naturally occurring parasitism on diamondback moth in field. Seven species of parasitoid wasps (five larval and two pupal parasitoids) and two species of hyperparasitoid wasps were determined. The parasitoids included the Braconids *Cotesia vestalis* (Kurdjumov), *Bracon hebetor* Say and *Apanteles* sp., the ichneumonid, *Diadegma semiclausum* (Hellen), and the eulophid, *Oomyzus sokolowskii* (*Kurdjumov*) as larval parasitoids, and the ichneumonids *D. collaris* (Gravenhorst) and *Diadromus subtilicornis* (Gravenhorst) as pupal parasitoids. In addition, the pteromalids *Mokrzeckia obscura* Graham and *Pteromalus* sp. were identified as the hyperparasitoids, which in turn parasitised *C. vestalis*. The most predominant species were *C. vestalis* and *D. semiclausum* with the proportional abundance of 0.43 and 0.42, respectively. Percentage parasitism varied significantly between host plants, but not between areas; the parasitised proportion of *P. xylostella* larvae fed on common cabbage was significantly greater than that on cauliflower (0.42 vs. 0.34). The mean percentage parasitism varied between 14.5 and 68.4 for different fields, and accounted for 37.4% of *P. xylostella* population on an average. The greatest parasitism was achieved by *C. vestalis*, *D. semiclausum* and *O. sokolowskii*, with a parasitism of 21.0, 12.9 and 3.5% of field populations of *P. xylostella*, respectively. These findings illustrated the important role of parasitoids for sustainable management of diamondback moth.

Ameri *et al*. (2015) recorded the new genus *Bracon fabricius*, 1804 (Hymenoptera: Braconidae) in Southern Iran by using Malaise trap. A total of 10 species belonging to 6 subgenera were collected and identified, of which 2 subgenera (*Ophthalmobracon* Tobias, 1957, and *Osculobracon*) and 6 species are recorded for the first time from Iran. The newly recorded species from Iran were as follows: *Bracon* (*Glabrobracon*) *ahngeri* Telenga, 1936; *Bracon* (*Habrobracon*) *didemie* (Beyarslan, 2002); *Bracon* (*Ophthalmobracon*) *ophthalmicus* Telenga, 1933; *Bracon* (*Osculobracon*) *erzurumiensis* Beyarslan, 2002; *Bracon* (*Osculobracon*) *osculator* Nees 1811; and *Bracon* (*Glabrobracon*) *obscurator* Nees, 1811.

### 2.2 Preference of *Bracon* spp. on *Helicoverpa armigera* Hub. feeding on different hosts.

Griggs(1959) reported longevity of female was longer than male as female had the capacity to recover resources by reabsorbing eggs and were also larger and heavier than males due to slower rate of weight loss than that of males.

Hagstrum and Smittle (1978) reported once the host was located by female *B. hebetor*, they injected venom, which resulted in complete paralysis of host within 25 minutes.

Taylor (1988) studied on effect of host species (*Anagasta kuhniella* and *Plodia interpunctella*) on the functional and ovipositional responses of *Bracon* spp. and its preference between these host types. The wasp preferred to paralyse *Plodia interpunctella* rather than *Anagasta kuhniella*. Similarly more eggs were laid on *Anagasta kuhniella* than on *Plodia interpunctella.*

Shonouda and Nasr (1998) reported ovipositing females were found to locate their hosts probably via trails containing semiochemicals produced in the mandibular gland of the host larvae.

Magro and Parra (2001) studied the biology of *B. hebetor* on seven lepidopteran species *viz*., *A. kuehniella* (*Ephestia kuehniella*), *Corcyra cephalonica* and *Sitotroga cerealella* and *Diatraea saccharalis*, *Heliothis virescens*, *Anticarsia gemmatalis* and *Spodoptera frugiperda*. Duration and viability of the biological cycle (egg-adult) were affected by the host used. *A. kuehniella* and *C. cephalonica* were similar hosts for *B. hebetor* rearing, producing insects with life cycle of 12.8 days, viability around 90% and excellent paralyzing and parasitism capacities.

Gunduz and Gulel (2004) studied on the effect of host species (*Galleria mellonella* and *Ephestia kuehniella*) and food types (host larvae, 50% honey solution and host larvae + honey solution) on longevity of *B. hebetor* (Say). The females fed with all food types lived longer than the males. The means of adult longevity of females reared on *G. mellonella* and fed only with host larvae, honey solution or host larvae + honey solution were 29.39, 49.78 and 33.56 days, while in males, they were 7.22, 25.56 and 26.56 days, respectively. The adult longevity of females reared on *E. kuehniella* and fed with host larvae, honey solution or host larvae + honey solution was 27.44, 46.22 and 32.56 days, respectively, while those for males were 5.56, 25.94 and 25.17 days, respectively.

Gunduz and Gulel (2005) reported effect of *B. hebetor* age on fecundity and sex ratio. *G. mellonella* and *E. kuehniella* were used as host species. The fecundity of the female parasitoid did not change significantly during the first 5 days of the female's lifespan, but it decreased significantly thereafter. Under laboratory conditions, the offspring sex ratio was male biased on both host species. The fecundity of the female parasitoids reared on late stage larvae of *G. mellonella* was higher than that on *E. kuehniella*.

Milonas (2005) reported influence of initial egg density and host size on the development of *B. hebetor* on three different host species. Wasp eggs at a range of densities, were placed on larvae of different weight of three Lepidoptera host species namely *Adoxophyes orana* (Tortricidae), *Plodia interpunctella* (Pyralidae) and *Lobesia botrana* (Tortricidae). On *A. orana* survival of immature parasitoids was very low at all densities and different host weights. On *L. botrana* survival progressively reduced as egg density increased at both host weights examined for this host. Survival on *P. interpunctella* was significantly affected by egg density but not by host weight. Initial egg density had a significant effect on the size of emerging adults from each rearing host. Smaller adult parasitoids emerged as egg density per larva increased. Larval host weight of *P. interpunctella* and *A. orana* had a significant effect on the size of emerging adult parasitoids mainly at the higher egg densities.

Kares *et al.* (2009) studied preference of *B. brevicornis* Wesm. on three lepidopteran larvae *viz.*, corn borers, *Ostrinia nubilalis* Hb., *Sesamia cretica* Led. and black cut worm, *Agrotis ipsilon.* Mean numbers of parasitoid's progeny per host larva were 9.6 (on *O. nubilalis*), 9.3 (on *S. cretica*) and 7.3 (on *A. ipsilon*) when host larvae were exposed daily to the parasitoid female. Respective figures when host larvae were exposed every two days reached 17.1, 11.4 and 6.4 individuals. Sex ratio (male:female) was found to be 1:0.9, 1:0.3 and 1:0.6, when the parasitoid was reared on *O. nubilalis*, *S. cretica* and *A. ipsilon*, respectively at one day exposure period. The respective sex ratios at 2-day exposure period were 1:0.4, 1:0.5 and 1:0.3. Among the studied three insect hosts, *O. nubilalis* seemed to be the recommended host for mass rearing of *B. brevicornis*.

Landge *et al*. (2009) studied on comparative biology of *B. hebetor* Say on *Corcyra cephalonica* Stainton and *Opisina arenosella* Walker. In *B. hebetor* Say mating frequently occurs during day and night. Pre-oviposition period on *C. cephalonica* and *O. arenosella* lasted for 15.5 and 17.8 hours, oviposition period 34.7 and 26.5 days and post-oviposion period 4.75 and 2.8 days. Eggs were deposited singly on ventral side of both the host larvae with an average of 423.3 and 33.7 eggs. Incubation period, larval period, pre-pupal period and pupal period lasted for 23.32 hours and 24.26 hours, 64.8 hours and 72.48 hours, 0.46 days and 0.93 day and 4.37 and 5.3 day on *C. cephalonica* and *O. arenosella*, respectively. Larvae passed through five instars, pupation took place in silken cocoon near vicinity of the host. Male and female adults from *C. cephalonica* and *O. arenosella* survived 14.2 and 37.9; 12.05 and 20.85 days, respectively. Life-cycle completed within 8.25 and 10.56 days on *C. cephalonica* and *O. arenosella*, respectively. Sex-ratio of male to female adult was 1.66:1 on *C. cephalonica* and 1.30:1 on *O. arenosella*.

Ghimire and Phillips (2010b) evaluated 12 potential lepidopteran host species for the development and reproduction of *B. hebetor viz.*, Indianmeal moth, *Plodia interpunctella* (Hubner), Mediterranean flour moth, *Ephestia kuehniella* (Zeller), almond moth, *E. cautella* (Walker), rice moth, *Corcyra cephalonica* (Walker), navel orangeworm, *Amyelois transitella* (Stainton), greater wax moth (laboratory reared and commercial), *Galleria mellonella* (Linnaeus) (all Pyralidae); tobacco budworm, *Heliothis virescens* (Fabricus), corn earworm, *Helicoverpa zea* (Boddie), beet armyworm, *Spodoptera exigua* (Hubner) (all Noctuidae); webbing clothes moth, *Tineola bisselliella* (Hummel) (Tineidae); and Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Gelichiidae). *B. hebetor* females were introduced singly into arenas and given a full-grown host larva every day for five consecutive days. Paralysis of the host larvae and oviposition by *B. hebetor* females were significantly affected by host species. The cumulative fecundity in the five days period was highest on *A. transitella* (106.42+or-5.19) and lowest on *T. bisselliella* (9.64+or-1.28). The egg to adult survivorship and progeny sex ratio were also significantly affected by the host species. The highest percentage of parasitoid survival to the adult stage was on *A. transitella* (84.07+or-2.26) and zero on *T. bisselli*ella. Egg to adult development time was shortest on *E. cautella* (9.75+or-0.25 d) and longest on *G. mellonella* (12.63+or-0.28 d). *B. hebetor* females can use a wide range of lepidopteran hosts for paralysis and oviposition. However, *B. hebetor* cannot necessarily develop and reproduce on all host species that it can paralyze and oviposit on.

Thanavendan and Jeyarani (2010) studied the biology of *B. brevicornis* on different host larvae *viz.*, *E. vittella* and *H. armigera* at different temperature *viz*., 20, 25, 30 35 $^{0}$C and room temperature , on the developmental in comparison with the laboratory host, *C. cephalonica*. Temperature regime of 25 $^{0}$C is highly suitable with a short life cycle of 8.22, 8.27 and 8.07 days respectively followed by room temperature (ranged between 22 to 32 $^{0}$C). Among the host larvae studied, *C. cephalonica* and *E. vittella* were found to be more suitable with maximum number of eggs, grubs, cocoons, adult males and females respectively. *H. armigera* was next in the order of preference recording less number of eggs, grubs, cocoons, and adults. The developmental period was also found to be less in *C. cephalonica* and

*E. vittella* followed by *H. armigera*. Though the life cycle is very short at 35 $^0$C, the progeny production was comparatively less with more males than females. At 20 $^0$C the life cycle was prolonged with minimum progenies yielding more males than females.

Alam *et al*. (2014) recorded the duration of different developmental stages and other related parameters of *B. hebetor* reared on the larvae of *G. mellonella*. The biology of the ecto-endo larval parasitoid, *Bracon hebetor* (Say), was studied on the wax moth, *Galleria mellonella* (F.) larva at 25±2°C, 75±5% RH and 12 hr photoperiod. The mean incubation period was 1.48 days and larval period 3.17 days. The pupal period lasted for 4.35 days with a range from 4.0 - 6.0 days. The mean development period of the parasitoid on *G. mellonella* was 9.60 days. The females lived longer period (20.00 days) than males (14.40 days). They found female ovipositor length was 0.48 mm.

Ghimire and Phillips (2014) assessed the reproductive performance of the parasitoid, *H. hebetor* in a series of laboratory experiments using six different pyralid host species, Indian meal moth, *Plodia interpunctella* (Hubner), Mediterranean flour moth, *Ephestia kuehniella* (Zeller), almond moth, *Ephestia cautella* (Walker), rice moth, *Corcyra cephalonica* (Stainton), navel orangeworm, *Amyelois transitella* (Walker), and greater wax moth, *Galleria mellonella* L. Paralysis of hosts by *H. hebetor* females was significantly affected by host species. *H. hebetor* paralyzed >95% of the preferred host larvae that were offered and also used ~90% of those for oviposition. Daily fecundity was highest on *G. mellonella* (22.1+or-0.4) and *C. cephalonica* (21.6+or-0.3), and lowest on *E. cautella* (13.4+or-0.2). The egg to adult survivorship and progeny sex ratio were also significantly affected by the host species. The highest percentage of parasitoid survival was on *A. transitella* (75.7+or-2.0) and *C. cephalonica* (75.4+or-2.5), and lowest on *G. mellonella* (49.7+or-4.8). *H. hebetor* females can paralyze and lay eggs on several pyralid species, but it cannot necessarily develop and reproduce optimally on all host species that it can paralyze and parasitize.

Saadat *et al*. (2014) studied on the comparison of the developmental time of *B. hebetor* reared on five different lepidopteran host species *viz*., *Ectomyelois ceratoniae*, *Plodia interpunctella*, *Ephestia kuehniella*, *Helicoverpa armigera* and

*Malacosoma disstria*. The parasitoid performed better on stored product pests, such as *E. kuehniella* and *P. interpunctella*, than field crop pests, such as *H. armigera* and *M. disstria*. Percentage egg hatch, rate of development, off-spring sex ratio and adult dry mass *Bracon hebetor* did much better when it parasitized stored product insects than field crop insects (P<0.05).

2.3 **To study the ovipositional preference of *Bracon* spp. on second and fourth instars of host insects.**

Alam *et al*. (2014) recorded the duration of different developmental stages and other related parameters of *B. hebetor* reared on the larvae of *G. mellonella*. The biology of the ecto-endo larval parasitoid, *Bracon hebetor* (Say), was studied on the wax moth, *Galleria mellonella* (F.) larva at 25±2°C, 75±5% RH and 12 hr photoperiod. The mean incubation period was 1.48 days and larval period 3.17 days. The pupal period lasted for 4.35 days with a range from 4.0 - 6.0 days. The mean development period of the parasitoid on *G. mellonella* was 9.60 days. The females lived longer period (20.00 days) than males (14.40 days). They found female ovipositor length was 0.48 mm.

Dabhi *et al*. (2013) studied on reproductive parameters of *Bracon hebetor* Say on seven different hosts (Rice moth (*Corcyra cephalonica*), Stainton Angoumois grain moth (*Sitotroga cerealella)*, Oliver greater wax moth (*Galleria mellonella)*, Linnaeus spotted pod borer *(Maruca testulalis*), Geyer gram pod borer (*Helicoverpa armigera*) (Hubner), Hardwick tobacco leaf eating caterpillar (*Spodoptera litura* Fabricius) and okra fruit borer (*Earias vittella* Fabricius). *C. cephalonica* was the most suitable host for the development of *B. hebetor* among the host species tested regarding the biological parameters studied (duration of different life stages, fecundity, egg hatching percentage and sex ratio) followed by *S. cerealella, G. mellonella, M. testulalis, E. vittella, H. armigera* and *S. litura.*

Kahrarian (2012) reported occurrence of pod borer *Heliothis viriplaca* in relation to the phenology of chickpea in rain-fed chickpea fields in Iran. Population density of *H. viriplaca* was 95% while population density of *Helicoverpa armigera*and *H. peltigera* were 2 and 3%, respectively. Fully grown larvae of *H. viriplaca* were parasitized by the *Habrobracon hebetor.*

Saxena *et al*. (2012) studied on suitability of larval instars of *H. armigera* to the parasitoid *H. hebetor*. This parasitoid attacked third to sixth instars, though fourth and fifth instar larvae were found most suitable with 100% parasitism and development to adults. Parasitoid developmental time was longest in fifth instar (9.1 days) compared to other instars (8.1-8.9 days). Fifth instar larvae resulted in highest numbers of cocoons and adult emergence. Among the seven lepidopteran species *Corcyra cephalonica*, *Galleria mellonella* and *H. armigera* were the most suitable hosts with 100% parasitism and development to adults of *H. hebetor*. Though there was 23.3% parasitism, there was no parasitoid development was observed on *Spodoptera litura*. Development of *H. hebetor* was most rapid in *C. cephalonica* (8.7 days), and longest in *G. mellonella* (9.3 days). Parasitoids that developed on these hosts resulted in highest numbers of cocoons and adult emergence.

### 2.4 To study the biology of *Bracon hebetor* Say (Hymenoptera : Braconidae) on various lepidopteran larvae under laboratory conditions.

Akinkurolere *et al*. (2009) studied on parasitism and host-location preference of *Habrobracon hebetor* (Hymenoptera: Braconidae). *H. hebetor* was able to parasitize all instars (first through fourth) of *P. interpunctella*, but significantly fewer early instars (first through fourth) were parasitized. Parasitized third and fourth instars were more profitable to *H. hebetor*, irrespective of refuge or choice factors, as significantly more adult parasitoids emerged from third and fourth instars. *H. hebetor* females consistently showed a preference for fourth instars of *P. interpunctella* when they were offered a choice between early and late host instars in arenas both with and without a refuge. Generally, parasitization of early instars was higher in no-choice than in choice tests.

Antolin *et al*. (1995) studied on variable sex ratios and ovicide in an outbreeding parasitic wasp. It has been hypothesized that *Bracon hebetor* females produce proportionately more female offspring under conditions of superparasitism (when laying eggs on previously parasitized hosts) because daughters are reproductively more valuable than sons when resources are limiting and adult body sizes are reduced. This hypothesis was re-examined by measuring the effects of body size on male and female performance and by monitoring the sex ratios and clutch sizes of individual females. *B. hebetor* females were provided with 5$^{th}$ instar larvae of *Plodia interpunctella*. Sex ratios were more female-biased on superparasitized hosts, but the difference arose as a consequence of 2 aspects of oviposition behaviour. First, male eggs were laid later within ovipositional sequences, and second, females laid smaller clutches when superparasitizing. A larger sex-ratio shift towards male progeny was seen, however, in females that committed ovicide (i.e. killed some of another's eggs by piercing them with the ovipositor). The offspring sex ratios of ovicidal females were much less female-biased because these females laid male eggs earlier in the ovipositional sequence. Ovicidal females shifted their sex ratios whether superparasitizing or ovipositing alone. None of the females killed their own eggs, even though they were observed probing among them with their ovipositors. It is hypothesized that oviposition behaviour and sex ratio in *B. hebetor* may be grouped into 2 syndromes: ovicidal and non-ovicidal. The variation in sex ratio and ovicide may be a consequence of density-dependent selection, favouring non-ovicidal behaviour when population density was low and ovicidal behaviour when the density was high and competition for larval resources is acute.

Dabhi *et al*. (2013) studied on reproductive parameters of *Bracon hebetor* Say on seven different hosts (Rice moth (*Corcyra cephalonica*), Stainton Angoumois grain moth (*Sitotroga cerealella)*, Oliver greater wax moth (*Galleria mellonella)*, Linnaeus spotted pod borer *(Maruca testulalis*), Geyer gram pod borer (*Helicoverpa armigera*) (Hubner), Hardwick tobacco leaf eating caterpillar (*Spodoptera litura* Fabricius) and okra fruit borer (*Earias vittella* Fabricius). *C. cephalonica* was the most suitable host for the development of *B. hebetor* among the host species tested regarding the biological parameters studied (duration of different life stages, fecundity, egg hatching percentage and sex ratio) followed by *S. cerealella, G. mellonella, M. testulalis, E. vittella, H. armigera* and *S. litura.*

Darwish *et al*. (2003) reported the choice of probing sites by *B. hebetor* Say (Hymenoptera: Braconidae) foraging for *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae). *B. hebetor* appears to be directed to the habitat of its host through chemical cues originating from the host larvae, frass and adults. These cues elicit a series of directed responses by the female. Flour containing 30 day old larvae was preferred by *B. hebetor* females. This was followed by the flour containing the frass, then the adult host, and finally the flour containing 10 day old larvae. It appeared that cues produced by young larvae were the weakest whereas cues produced by older ones were the strongest. Feeding seemed to be important in the location of the proper searching site. Although the cues were normally learned by the immature stages of the parasitoid, and were subsequently manifested in their responses as adults, adult experience increased the ability of the parasitoid to locate the suitable habitat for searching.

Farag *et al*. (2012) studied on life history of *Habrobracon hebetor* Say parasitizing *Cadra* (*Ephestia*) *cautella* (Walker) (Lepidoptera: Pyralidae) on dried date fruits. Adult longevity was 7.9 and 6.6 days for female and male, respectively. Pre-ovopositional and ovipositional periods lasted <12 h and 7.4 days, respectively. Total number of eggs/female was 69.3, with a mean of 9.45 eggs/day. Mean durations of immature stages reached 14.99 hrs, 2.48 and 5.65 days for egg, larval and pupal stages, respectively. Egg hatchability, pupation and adult emergence were recorded to be more than 95%. The larvae of *H. hebetor* could externally parasitize all larval instars of *C. cautella*. However, the parasitoid preferred late larval instars of *C. cautella*. Parasitism rate was significantly different among the instars.

Forouzan *et al*. (2003) studied on the biology of *Habrobracon hebetor* Say (Hym.: Braconidae) on *Galleria mellonella* larva under laboratory conditions. The biology of *H. hebetor* (*Bracon hebetor*) (at 28+or-0.5 $^{0}$C, 65+or-5% RH, 16:8 h L:D photoperiod, with the host *G. mellonella* larva) indicated that this parasitoid completed its development in 12.09 days (egg 1.77+or-0.03 days; larvae 3.43+or-0.04 days and pupa 6.89+or-0.05 days). Newly emerged female parasitoid responded well to the host larvae. The adult lived longest when provided with both honey and water. Without food, they survived for less than 5 days. Results showed that during the oviposition period, they deposited eggs all day and night. There were no significant differences in reproduction and longevity between virgin (74.4+or-11.27 and 16.67+or-1.02) and mated (84.4+or-10.36 and 16+or-1.4) females.

Fukushima *et al*. (1990) reported new non-cyclic homo-diterpene from the sting glands of *B. hebetor* Say. A novel homo-diterpene was found in an extract of the sting glands (a complex of the venom gland and Dufour's gland) of the parasitoid *B. hebetor*, along with beta-springene and n-alkanes, and was identified as E,E-11-ethyl-7,15-dimethyl-3-methylene-hexadeca-1,6,10,14-tetraene.

Ghimire and Phillips (2010a) developed a mass rearing procedure for *H. hebetor* as a biological control agent against *P. interpunctella*. A density of eight male-female pairs of *H. hebetor* produced a higher number of progeny (188 adults) on 50 last-instar *P. interpunctella* larvae than the densities of one and two pairs of *H. hebetor*. Similarly, in a host density experiment, a density of 50 last-instar *P. interpunctella* larvae produced a significantly higher number of parasitoid progeny (160 adults) among the tested host densities when two pairs of *H. hebetor* were used. The size of the rearing containers, a glass jar with a volume of 236.6 ml (8 U.S. ounce "jelly jar"), produced a relatively higher number of parasitoid progeny (166 adults) than other sizes of containers when two pairs of *H. hebetor* were used. The parasitoid's secondary sex ratio was female-biased in all experiments and there were no significant effects on sex ratio from variation in parasitoid density, host density, or size of the rearing containers.

Gul and Gulel (1995) further studied the biology of parasitoid *B. hebetor* (Say) and the effect of host larval size on fecundity and sex-ratio. *B. hebetor* were reared in the laboratory at 25 +or- 2 $^{0}$C and 55-60% RH on *Galleria mellonella*. An average of 12.0 days was required for the completion of its development from egg to adult. The eggs hatched within 2-3 days after oviposition. The larval and pupal stages were completed within 2-3 and 6-9 days, resp. Survival from egg to adult was about 24%. The highest percentage mortality occurred at the larval stage. Under laboratory conditions, the mean adult longevities of mated females and males were 13.3 and 10.2 days, resp. The total mean production of progeny was 16.5 adults, and 62% of these were females. The change in host-larval size did not produce an important effect on the progeny production of females, however, it did have some effect on the sex ratio.

Gurbuz and Aksoylar (2006) studied on reproduction capacity and sex ratio of *B. hebetor* (Say) parasitoid on *G. mellonella* (L.) under laboratory conditions of

30+or-2 $^{0}$C, 55-60% relative humidity (RH) and 12 h (L:D) photoperiod. The hatching of the parasitoid continued for approximately 3.5 days. The pupal period was completed after the 8$^{th}$ day. The adult males lived an average for 7.5 days, while the adult females lived for 20 days. An adult female laid approximately 80.85+or-05 eggs during its whole life and the sex ratio was 1:1.83.

Jervis *et al*. (1994) studied on the post-reproductive life in the parasitoid *B. hebetor* (Say). The longevity of females of *B. hebetor* after reproduction was studied in a series of laboratory experiments at 30 $^{0}$C, 70-80% RH and LD 18:6, with various regimes of host (larvae of *P. interpunctella*) availability. During post-reproductive life, females continued to paralyse and feed upon hosts.

Jhansi and Babu (2003) studied comparative biology of *B. hebetor* Say in two host insects, namely *C. cephalonica* and *Maruca testulalis*, under laboratory conditions. The number of eggs laid, percentage of egg hatch, growth index and percentage of adult emergence were higher in *C. cephalonica*. In addition, a favourable sex ratio with comparatively higher number of females than males was also observed in *C. cephalonica*.

Kaur *et al*. (2009) studied on the biology of *B. hebetor* (Say), an ectoparasitoid of *Spodoptera litura* (F.) (Lepidoptera: Noctuidae) at 25+or-2 $^{0}$C, 75+or-5 per cent relative humidity and 12 hr photoperiod. The egg incubation period averaged 1.33 days and larval period 5.47 days. There was only 18.07 per cent pupation and the pupal period lasted 3.91 days, ranging from 3.16-4.41 days. There was 85.27 per cent adult emergence. The mean development period of the parasitoid on *S. litura* was 9.44 days. The females lived longer (33.49 days) than males (23.16 days). The oviposition period lasted for 32.66 days and the average fecundity was 90.38 eggs. The maximum eggs were laid between 7 and 18 days of oviposition. The egg density had an adverse effect on egg hatchability and larval survival. The parasitisation efficacy was highest at the sex ratio of 1:1 but decreased as the number of females vis-a-vis males increased.

Magro *et al*. (2006) studied on the biology of *B. hebetor* reared on 5$^{th}$ instars of *Anagasta kuehniella* (*Ephestia kuehniella*) (natural diet) and in vitro (artificial diet) was evaluated. *B. hebetor* had three instars in both diets, but the developmental time on the artificial diets was prolonged due to the increase in larval and pupal development times. Larvae grew faster on the natural host and required a lower food intake (2.7 micro l) compared to that required by the larvae feeding on the artificial diet (3.8 micro l).

Mostaghimi *et al*. (2012) observed the effect of different larval densities of *E. kuehniella* and *P. interpunctella* on the parasitic efficiency of *H. hebetor*. The efficacy of *H. hebetor* in parasitizing larva of the mill moth and of the Indian meal moth was evaluated at different densities of parasitoid (1, 2 and 4 pairs) and host larvae (1, 2, 4, 8, 16 and 32) in a growth chamber set at 25+or-1 $^{0}$C, 65+or-5 RH, and 14L:10D photoperiodism. When one pair of parasitoid was released, the number of eggs laid increased at the densities of 1, 2, 4 and 8 larvae of either host, respectively but, it decreased at the densities of 16 and 32 larvae of either host. Also, the number of emerged females and adults of wasp increased at the densities of 1, 2, 4 and 8 larvae of both hosts, respectively but, did not significantly increased at the densities of 16 and 32 larvae of either host. When two pairs of parasitoid were released, the highest number of eggs laid was observed at the density of 16 larvae of the mill moth. Whereas, the number of eggs laid at the densities of 4, 8, 16 and 32 larvae of the Indian meal moth were significantly higher than those for the other larval densities. Also, the number of emerged females and adults of wasp increased at the densities of 1, 2, 4, 8 and 16 larvae of either host, respectively but, they did not significantly increase at the density of 32 larvae for either host. When four pairs of the parasitoid released, the number of eggs laid at the densities of 8 and 16 larvae of either host was found significantly higher than those for the other larval densities. Also, the number of emerged females and adults of wasp increased at the densities of 1, 2, 4, 8 and 16 larvae of either host, respectively but, did not significantly increase for the density of 32 larvae in either host. Based on the results obtained it was concluded that at one pair of parasitoid treatment, a number of 8 larvae of either host, at the two and four pairs of parasitoid treatments, a number of either 16 or 32 larvae of either hosts formed the most suitable combinations for a mass rearing of *H. hebetor*.

NaKyoung *et al*. (2000) recorded effect of temperature on the development of *B. hebetor* parasitizing Indian meal moth. Development of *B. hebetor* parasitizing Indian meal moth (*Plodia interpunctella*) was studied at five temperature conditions (17, 20, 25, 28 and 32+or-0.5 $^{0}$C under a photoperiod of 16:8 (light:dark). Developmental period (mean+or-s.e.) of *B. hebetor* from egg to eclosion decreased from 28.6+or-0.50 to 9.3+or-0.09 days and 28.1+or-0.51 to 9.2+or-0.09 days for female and male, respectively), as the temperature increased from 17 to 32 $^{0}$C. The low temperature thresholds were estimated to be 14.0, 12.8, 15.1 $^{0}$C for development of the egg, larva and pupa, respectively. The thresholds for normal development (outside of the development boundary layer) were 14.0, 17.5, 15.1 $^{0}$C for the egg, larva and pupa, respectively, indicating that the larval stage is more sensitive to low temperature than the other stages.

Parra *et al*. (1994) reported flight response of *H. hebetor* (Say) (Hymenoptera: Braconidae) in a wind tunnel to volatiles associated with infestations of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae). The response of 2- to 5-day-old virgin and mated naive females of *H. hebetor* to host (*E. kuehniella*) volatiles in a wind tunnel was compared to the response obtained from identically aged virgin and mated females given an experience of selected host cues, including exposure to host frass for two minutes or to a host itself. Females exposed to hosts were allowed to antennate only, to sting and paralyse or to oviposit the host. None of the naive-virgin females flew to the 16-tube target chamber containing frass, while a significant number of the naive-mated females responded. Exposure to host frass or larvae significantly increased the number of virgin and mated females that responded to frass, but most of the females responded if they were first allowed to oviposit on a host. The flight response of mated 2- to 9-day-old females was compared after exposure to uninfested host diet, larvae, frass or cocoons. Frass was significantly more attractive than larvae or the diet, while cocoons were not attractive. Ether and dichloromethane extracts of host frass both elicited flight behaviour in *H. hebetor*.

Qiu *et al*. (2006) studied on effects of temperature on development, fecundity and longevity of *H. hebetor*. The adult longevity, development and fecundity of *B. hebetor* were observed at 15, 20, 25 and 30 $^{0}$C in laboratory. The developmental rate increased with the increasing temperature from 15 to 30 $^{0}$C. The longest duration of egg (9.50+or-1.39 days), larval (6.60+or-1.41 days) and pupal (23.71+or-2.63 days) stages was observed at 15, 20 and 15 $^{0}$C, respectively.

The longest longevity for female adult was 50.15+or-6.96 days observed at 15 $^0$C and the shortest was 9.20+or-3.12 days at 30 $^0$C. The longest longevity for male adult was 11.45+or-3.52 days observed at 15 $^0$C, and the shortest was 5.90+or-1.62 days at 30 $^0$C. In general, the adult longevity of female was longer than that of male. The maximum number of eggs laid per female was 208.50+or-40.12 at 25 $^0$C. The maximum emergence rate was 35.87+or-13.87% at 30 $^0$C. It could be concluded that temperature showed a significant effect on biological parameters of *H. hebetor*.

Radhika and Chitra (1996) reported that the longevity of adults of *B. hebetor* over two generations was greatest when fed with honey (20% of the diet). The number of eggs, larvae, pupae and adults was also increased by 20% honey.

SeungHun *et al*. (1999) studied life history of *B. hebetor* on *Plodia interpunctella* Hubner. The longevity of females (mean+or-SE) was 20.88+or-0.97 days. Females laid eggs from the first day after emergence and the oviposition period ranged from 11 to 27 days. However, 65% of the total number of eggs were laid in the first 10 days. The progeny sex ratio in the first 15 days was female-biased ranging from 0.51+or-0.08 to 0.88+or-0.02, but changed to male-biased ranging from 0.14+or-0.04 to 0.34+or-0.12. The overall sex ratio of progeny produced per female was estimated to be 0.66. The total number of progeny per female and net reproduction rate were estimated as 205.17+or-13.03 and 136.21, respectively.

Wang (1991) studied on the relationship between host size and sex ratio of *B. hebetor* (Hym: Braconidae). Laboratory studies showed that more eggs of *B. hebetor* were laid on larger larvae of *Plodia interpunctella* than on smaller ones and that the percentage of female progeny from larger hosts was also greater.

Yu *et al*. (2003) reported effect of host density on egg dispersion and the sex ratio of progeny of *B. Hebetor* infesting larvae of *P. interpunctella* (Hubner). Females appeared to allocate eggs in relation to host density to avoid laying more eggs than could complete development on a host. The dispersion pattern of the parasitoid ovipositions among hosts was influenced by host density. Multiple visitations and ovipositions by females on hosts caused a highly aggregated pattern at low-host densities. Hatch rate of eggs decreased as the number of eggs on a host increased. Females seemed to regulate progeny sex ratio (male/total) based on the number of eggs on the hosts and the clutch size of the hosts they encountered. However, the overall progeny sex ratio remained at approximately 0.5 regardless of host density, probably because the allocation of eggs was related to host density.

Zaki *et al*. (1994) observed some biological factors affecting the production of *B. brevicornis* Wesm. The number of progeny of *B. brevicornis* was greatly affected by the number of deposited eggs of *Bracon* females/host larva. The increase in the egg clutch size from 5 to 25 eggs/larva increased the progeny production. However, an increase in the egg clutch size of the parasitoid resulted in a decrease in the body size of female progeny. The ratios of parasitoid females-host larvae and the time of parasitization which led to optimum parasitism was studied. The most appropriate crowding level of females of *B. brevicornis* to full-grown larvae of *O. nubilalis* was also studied. The sex ratio of parasitoid progeny was significantly affected by changing the sex ratio of parent parasitoids, but there was no effect on the number of deposited eggs per host.

### 2.5 To construct the life table of *Bracon hebetor* on *Corcyra cephalonica* Stainton (Lepidoptera : Pyralidae).

Nikam and Pawar (1993) studied on life table and intrinsic rate of natural increase of *B. hebetor* Say (Hym., Braconidae) a key parasitoid of *Helicoverpa armigera* Hbn. on *Corcyra cephalonica*. The longevity of ovipositing females ranged from 32 to 42 days (mean 37.5 days). The total number of progeny produced was 158.9 (range 251-270). The maximum mean progeny production/day, m< sub>x</ sub> was 5.5. The innate capacity of increase was 0.215/female per day and the population multiplied 52.12 times with a mean generation time of 18.38 days.

Youm and Gilstrap (1993) reported life-fertility tables of *B. hebetor* reared on *Heliocheilus albipunctella* (Lepidoptera: Noctuidae). Mated females of *B. hebetor* lived an average of 24.7 days, oviposited for about 22 days and produced 173.7 adults with a 1:1 sex ratio. The estimated innate capacity of increase (r) and net reproductive rare (R< sub>o</ sub>) were 0.26 and 86.5, resp. The mean generation time was 17 days.

Singh *et al*. (2006) investigated the effect of different host (*C. cephalonica*) diets on the life table statistics of *B. hebetor*, a gregarious ectoparasitoid. The progeny sex ratio was female-biased when host diet was maize or wheat. The net fecundity rate (Ro) and total fecundity rate (Rt) were highest on host diet wheat, followed by maize, jowar (*Sorghum vulgare*) and rice. The innate capacity for increase in number (rc), intrinsic rate of increase (rm), finite rate of increase (lambda m) and weekly multiplication rate (rw) were highest on host diet wheat, followed by maize, jowar and rice. The doubling time was shorter on wheat than maize, jowar and rice, showing an inverse ratio to rm and rw. On the basis of life table statistics of *B. hebetor*, the diets of its host can be placed in order of their suitability for parasitoid population growth as: wheat > maize > jowar > rice.

Maafi and Hsin (2006) studied on demography of *H. hebetor* (Say) on two pyralid host species *G. mellonella* (L.) and *E.kuehniella* Zeller (Lepidoptera: Pyralidae) at 28 $^{0}$C in the laboratory. Data were analysed based on an age-stage, two-sex life table, to take both sexes and variable development into consideration. The intrinsic rate of increase (r), finite rate of increase (lambda), net reproductive rate (R0), gross reproductive rate (GRR), and mean generation time (T) of *H. hebetor* on *G. mellonella* were 0.1520 d-1, 1.1640 d-1, 12.5 offspring, 50.1 offspring, and 16.8 d, respectively. These values were not significantly different from the values obtained for *E. kuehniella*, i.e., 0.1375 d-1, 1.1473 d-1, 11.9 offspring, 54.9 offspring, and 18.2 d. The life expectancy of an *H. hebetor* egg was 10.6 d on *E. kuehniella* and 10.4 d on *G. mellonella*. On both host species, the maximum reproductive value of female *H. hebetor* occurred on the 12th day.

Eliopoulos and Stathas (2008) studied on life tables of *H. hebetor* parasitizing *A. kuehniella* and *P. interpunctella* (Lepidoptera: Pyralidae) in the laboratory. Various host density (daily supply of 1, 5, 15, and 30 full-grown host larvae) were used. The estimated parameters were the intrinsic rate of natural increase (rm), the net reproductive rate (Ro), the mean generation time (G), the finite capacity of increase (lambda), the gross reproductive rate (GRR), the doubling time (DT), the reproductive value (Vx), and the life expectancy (ex). The rm of *H. hebetor* proved to be significantly higher than those of its hosts at all host densities. When only one host per day was supplied, the wasp had the lowest reproductive potential, whereas it was maximized when 15 hosts per day were exposed. Maximum values of Ro and GRR were obtained at densities >=15 host larvae per day. Any increase in host supply above this threshold did not cause significant changes in life table parameters. Variation of rm as a function of host density can be described by the linear regression. Sex ratio of wasp progeny (females/total) ranged from 0.36 to 0.42, irrespective of host density or species. Newly emerged adults recorded maximum ex and Vx. The above information can be used to improve mass rearing programs and inoculative release applications of *H. hebetor* against moth pests of stored products.

Farag *et al*. (2015) studied on life tables of *B. hebetor* who found that the intrinsic rate (*rm*), the finite rate of increase ($\lambda$), the net reproductive rate ($R_0$) and the mean generation time (*T*) *B. hebetor* reared on *C. cephalonica* with 0.1942 female per day, 1.2133 times, 30.6 and 18.09 days, respectively.

## 2.6 To study the viability of *Bracon hebetor* (Say) cocoons during storage as Bracocards.

Farghaly and Ragab (1993) reported effect of low-temperature storage on pupae of *Bracon hebetor* Say. In two laboratory experiments carried out at 6 $^0$C and 60% RH, first experiment, one day-old pupae were stored for 1, 2, 3 and 4 weeks and in the second experiment, 1-, 2-, 5- and 7-day-old pupae were stored for one week. Low-temperature storage for 1, 2, 3 and 4 weeks induced 21.2, 55.6, 82.7 and 89.1% reduction in emerged adults, respectively. Prolonged storage periods resulted in a sex ratio in favour of males. The rate of adult emergence in 3 day old pupae (62.4%) was significantly lower than in the control (94.3%). Reduction in number of emerged females ranged between 43.2 and 63.8%. It was concluded that storing pupae of *B. hebetor* at 6 $^0$C affected the potential effectiveness of the parasitoid as a biological control agent.

Kyawt and Aung (2004) examined the effects of temperature and food on adult longevity of a Thailand strain of *B. hebetor* in laboratory conditions. When nothing, water or 50% honey solution was provided at 15-25 $^0$C, females lived significantly longer than males, except for the treatments with nothing or water at 25 $^0$C. Longevity of both sexes provided with nothing, water or honey solution, increased with decreasing temperature, except for those with water or nothing at

20-25 $^{0}$C. Both sexes provided with honey solution lived longer than those with nothing or water at temperatures tested. It may be due to this reason that *B. hebetor* is abundant in storages where no food source exists with relatively long longevity in dry condition.

Al Tememi and Ashfaq (2005) studied on the effect of low temperature storage on the fecundity and parasitizing efficacy of *B. hebetor* (Say). The effects of cold storage period (1, 2, 3 and 4 weeks) at varying temperatures (5, 10 and 20 $^{0}$C) on the mean number of adult emergence, sex ratio, longevity of adults, number of larvae developed per one female and number of parasitized larvae of host per female of the parasitoid *B. hebetor* were determined. A negative relationship between the number of emerged adults (females and males) and storage period for each tested temperature was recorded. The males were more than the females under all the tested temperatures and storage periods. The longevity of the adults females was reduced due to low temperature for all the tested periods. A negative relationship was observed between the number of larvae that developed from the emerged adults after storage as well as for the number of parasitized larvae of host for all storage periods.

Carrillo *et al*. (2005) reported about the cold hardiness of larval ectoparasitoid *H. hebetor* (Say) which are able to overwinter under extremely cold conditions. Feeding larvae and adults of *H. hebetor* had supercooling points (SCPs) at temperatures higher than those of eggs and pupae. Mean SCPs of females and males were equivalent, as were those of naked and silk-encased pupae. Feeding on honey prior to being subjected to low temperatures significantly increased the SCP of adult females by approximately 8 degrees C. Mortality of pupae and adults increased significantly whenever the temperature dropped below the mean SCP, indicating that *H. hebetor* does not tolerate freezing. For pupae and adults exposed to -12 and -5 degrees C, the hourly mortality rate increased with time of exposure. Pupae and adults exposed to -12 degrees C for different time intervals showed high mortality after only 1 d of exposure. At -5 degrees C, none survived 12 d of exposure.

Uwais *et al*. (2006) recorded influence of different storage conditions on the survival rate of adult wasps of reared *B. hebetor* Say. The best conditions included low temperature for 30 days. Periodic supplementation of food increased survival. Time of storage was important as the wasps died after 60 days of storage in low temperature.

HaoLiang *et al*. (2013) studied the performance of diapausing parasitoid wasps, *H. hebetor,* after cold storage. Mortality during storage increased with increasing storage duration, and the mortality of diapausing females was lower than that of nondiapausing females after 8, 12, and 16 weeks of storage. Longevity, egg laying, number of progeny produced, and time to 50% egg laying were all reduced, as compared with the culture females when parasitoids were reared at conditions that do not induce diapause. But, for females reared at $20^0$C at conditions that induce diapause, all of these quality parameters did not differ from those of culture insects when the storage duration was 8 weeks or less. The percentage of female F1 offspring was always lower for cold stored insects than for the culture insects. Presence of a male after cold storage did not impact any of the quality parameters measured. Thus, rearing parasitoids at 20 $^0$C and 10L:14D and then storing them for up to 8 weeks at 5 $^0$C would produce parasitoids that are similar to culture parasitoids, except that the percentage of females is lower than that in the cultures (36% vs. 52%).

Mousapour *et al*. (2013) studied the effect of cold storage on pupae of *H. hebetor* (Say). Cold storage is an appropriate way to extend the life of natural enemies such as insect parasitoids. The pupae of *H. hebetor* at the temperatures of 12, 9 and 4 $^0$C for a period of six weeks in five replicates were stored, there after the effect of storage on the percentage of emerged adults and the longevity of male and female adults was evaluated on weekly basis. The results of the survey conducted at 12 $^0$C showed that the percentage of adults emerged from the first week has dropped by almost half. *H. hebetor* pupae could be stored for a week at 9 $^0$C. At 4 $^0$C, a significant reduction was caused in the efficacy of the stored pupae and is not recommended.

**2.7 To study the management of diamonback moth, *Plutella xylostella* L. on cabbage crop by release of *Bracon hebetor*Say under field conditions.**

Heimpel *et al*. (1997) studied on reproductive isolation and genetic variation between two "strains" of *Bracon hebetor* (Hymenoptera: Braconidae). *B. hebetor* was released for the biological control of *Heliothis virescens* and *Helicoverpa* spp. on the island of Barbados. It was confirmed that *Heliothis virescens* was a more suitable host for the Barbados strain than for *B. hebetor*. However, a stored-grain infesting pyralid, *Plodia interpunctella*, was a more suitable host for the Barbados strain than was *H. virescens*.

Mohanty *et al.* (2000) released laboratory bred Hymenopterous parasitoids *viz., Bracon hebetor, B. brevicornis and Goniozus nephantidis* in the coconut orchards infested by the black-headed caterpillar, *Opisina arenosella* (Cryptophasidae; Lepidoptera). Releases were made at fortnightly interval at 15, 20 and 25% of the pest population in four villages (Bramhagiri, Biraharekrushnapur, Batagaon and Kanthapur) in Puri district of Orissa during 1996 and 1997. *O. arenosella* populations were maximum during January and minimum in September. The most effective control of the pest was achieved, when the parasitoids release were 20% of the pest population. The parasitization ability of *B. hebetor* and *B. brevicornis* was at par, followed by *G. nephantidis.* Searching ability was higher in *Bracon* spp., whereas longevity was higher in *Goniozus*.

Mohanty *et al*. (2001) further studied on the management of brinjal shoot and fruit borer, *Leucinodes orbonalis* Guen. by release of *B. brevicornis* Wesm. in the field in an experiment conducted in Orissa, India during 1997-99 on aubergine *cv*. Black Beauty-102 using *B. brevicornis* as a biological control agent. Shoot (0.2-10.2%) and fruit (0.1-5.1%) damage was reduced in the parasitoid released field compared to the control during 1997-98. Similar results were obtained during 1998-99. The percent reduction in shoot and fruit damage gradually increased with the number of releases along with the age of the plants.

Rajamanickam *et al*. (2002) worked on the integrated pest management of coconut leaf eating caterpillar *Opisina arenosella* Walker at Dharapuram by administering the root feeding of biopesticide Azadiractin F5% @ 10 ml+10 ml water and inundative release of larval parasitoids *B. brevicornis*, *Goniozus* *nephantidis* and pupal parasitoid *Trichospiluspupivora* of recommended dose at 21 days interval in two phases for each treatment. The results revealed that estimated mean pest population/palm significantly reduced from 785.60 to 210.50 at 21 days after 1st root feeding of bio pesticide. It reduced further from 210.50 to 48.20/palm at 21 days after the 1st release of parasitoids. Further more reduction of *O. arenosella* was observed from 11.45/palm to 4.35 at 21 days after the completion of 2nd phase of Azadirachtin F5 treatment and release of parasitoids. Consequently the population build up all the three parasitoids was achieved from 3.65%, 2.80% and 1.465% to 29.40%, 16.96% and 6.25% respectively.

Wuhrer and Zimmermann (2007) studied on biological control of the European Corn Borer, *Trichogrammabrassicae* are being selected and used against the ECB. New pest lepidoptera like *Helicoverpa armigera* could be controlled by releasing indigenous *T.* species. For the first time the option of using a larval parasitoid *B.brevicornis* was being considered which would support and sustain the biological control of the ECB.

Sharma and Srivastava (2011) studied on the seasonal incidence and natural enemies of leaf webber cum fruit borer, *Pempelia morosalis* (Saalm Uller) on Jatropha in Vindhyan region. Highest natural parasitisation of leaf webber by *Tachinid* spp. was 35.9%, while 33.4% larvae were parasitized by *Bracon hebetor*. Parasitism of leaf webber by *tachinid* fly and *B. hebetor* showed positive correlation. Peak incidence of leaf webber was during mid of September with a mean population of 5.80 larvae/5 plants with corresponding 26.5% plant damage. Maximum parasitisation of leaf webber by *Tachinid* spp. and *B. hebetor* was 36.0 and 28.4%, respectively and negative correlation was found between them.

Mahmudunnabi *et al*. (2013) analysed integrated pest management package against pod borer, *Helicoverpa armigera* Hubner infesting chickpea in which different biorational based IPM packages was evaluated *viz*., IPM package 1 (P1) comprising pheromone trapping of *H. armigera* along with sequential release of biocontrol agents (*Trichograma evanescens* +*Bracon hebetor* @ 1 jar (1000-1200 adults)/ha/week) and spraying of *Bacillus thuringiensis* (Bt) @ 0.4 g/litre of water, IPM package 2 (P2) consists of pheromone trapping in addition to sequential release of bio-control agents and spraying of HaNPV @ 0.1 g/litre of water against this pest attacking chickpea. The best performance reducing 68.20% pod damage over control and provided significantly the highest yield (1832.20 kg/ha) was recorded in P2. Consequently, the highest benefit cost ratio (BCR) (2.11) was also recorded from this package. Hence, biocontrol agent release along with installation of sex pheromone traps and spraying of HaNPV recommended for effective management of pod borer attacking chickpea.

Baoua *et al*. (2014) experimented on augmentative biological control of pearl millet head miner (*Heliocheilus albipunctella*) by *Habrobracon hebetor* releases. The release of parasitoids consisted of placing jute bags containing pearl millet grain and flour with parasitized host larvae near pearl millet fields. Based on a study of 6634 individual pearl millet heads collected at harvest in 12 farmers' fields in southern Niger in 2010, they demonstrated (i) a strong negative correlation between pearl millet head damage (mining) and grain yield and (ii) that parasitism by *H. hebetor* reduced grain losses by, an average, 34% (comparison of infested millet heads with/without parasitism) along with reduction in millet head miners in subsequent generations. This study provided a quantitative description of the negative impact of millet head miner infestations on pearl millet grain yields and of benefits on grain yield of parasitism by *H. hebetor*.

# CHAPTER – III

# MATERIALS AND METHODS

The present investigation entitled **"Studies on the host variability and ovipositional behaviour of larval ecto-parasitoid, *Bracon* spp. (Hymenoptera : Braconidae) at Raipur, Chhattisgarh"** was conducted in the biocontrol laboratory, Department of Entomology, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya Raipur (Chhattisgarh) during the year 2015-16 and 2016-17 with the following of objectives:-

3.1 To record the naturally available species of *Bracon* on few cereals, legumes, vegetables and fruits at Raipur, Chhattisgarh ecosystem.

3.2 Preference of *Bracon* spp. on *Helicoverpa armigera* Hub. feeding on different hosts.

3.3 To study the ovipositional preference of *Bracon* spp. on second and fourth instars of host insects.

**Apart from the above objectives studies on the following aspects were also under taken:**

3.4 To study the biology of *Bracon hebetor* Say (Hymenoptera : Braconidae) on various lepidopteran larvae under laboratory conditions.

3.5 To construct the life table of *Bracon hebetor* on *Corcyra cephalonica* Stainton (Lepidoptera : Pyralidae).

3.6 To study the viability of *Bracon hebetor* (Say) cocoons during storage as Bracocards.

3.7 To study the management of diamonback moth, *Plutella xylostella* L. on cabbage crop by release of *Bracon hebetor* Say under field conditions.

### 3.1 Location of study

All laboratory experiments were carried out in the Biocontrol laboratory, Department of Entomology, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya Raipur (C.G.) during the year 2015-16 and 2016-17.

### 3.1.1 Geographical Location Raipur

Raipur is situated in mid eastern part of Chhattisgarh at a latitude of $21.16^0$ North and $81.36^0$ East and 289 meters above mean sea level.

### 3.1.2 Climate of Raipur

The experimental site, Raipur comes under the seventh agro-climatic region of India i.e. eastern plateau and hills which is termed as sub humid with hot summer and cold winter. The source of rainfall is South western monsoon. It receives an average annual rainfall of 1200-1400 mm, mostly (85%) concentrating during the period of June to September. A few showers expected during winters and occasionally during summer months. May is the hottest and December is the coolest month of the year. The weekly maximum temperature rises up to $46^0$C during summer and minimum temperature reaches as low as $6^0$C during winter season.

## 3.2 Experimental Details

### 3.2.1 To record the naturally available species of *Bracon* on few cereals, legumes, vegetables and fruits at Raipur, Chhattisgarh ecosystem.

To record the naturally available species of *Bracon*, on cereals like paddy and maize legumes like pigeon pea and chickpea, vegetables like brinjal, tomato, cabbage and okra, fruits like ber, guava, sapota and mango were selected at Raipur, Chhattisgarh. From these crop ecosystems *Bracon* spp. were collected by placing five fifth instar larvae of rice meal moth, *Corcyra cephalonica* in small plastic container (100 ml) and secured tightly with muslin cloth with rubber band (sandwich method) at various places under different crops ecosystem. After 48 hours of exposure, the containers were brought back to the laboratory and observed for egg laying and emergence of parasitoid species. Different *Bracon* spp. were collected at fortnightly interval and sent for identification at NBAIR, Bengaluru, Karnataka.

### 3.2.2 Preference of *Bracon* spp. on *Helicoverpa armigera* Hub. feeding on different hosts.

A study was conducted on detailed life cycle and preference of *Bracon* spp. on different Lepidopteran larvae during 2015-16. Host larval population of

*Helicoverpa armigera* Hub. was collected from different fields (chick pea, pea, pigeon pea, okra and tomato) and reared on their respective natural food to obtain healthy and uniform aged (fourth instar) larvae. One pair of newly emerged *Bracon* spp. was placed inside a glass jar (15cm x 9cm) covered with a piece of white muslin cloth over which one full grown larva reared on respective hosts were placed. After placing the larvae glass, jar was again covered with another piece of white muslin cloth of same size and kept in position with the help of rubber bands. Five replicates were used for each host species. After 48 hours, the larvae of each host species were removed gently without damage and was kept individually in petriplates (9 cm diameter). Observations were recorded on number of eggs laid (fecundity), percentage of hatching, number of larvae emerged, larval and pupal duration along with their biometrics. The duration of life cycle of *Bracon* spp. reared on *Helicoverpa armigera* Hub. feeding on different hosts and sex ratio was also investigated. Data on egg hatching (%), eclosion (%), viability (%), survivorship (%) and fecundity were analysed in Completely Randomized Block Design after appropriate transformation.

**3.2.3 To study the ovipositional preference of *Bracon* spp. on second and fourth instars of host insects.**

Larval population of *Helicoverpa armigera and Spodoptera litura* Fab. were collected from the fields and reared on their respective natural food to obtain healthy and uniform aged (second and fourth instar) larvae. Five larvae from each instar were taken and kept under a small petridish above the muslin cloth tied on a basin and replicated eight times. Ten pairs of larval ecto-parasitoid *Bracon* spp. were collected with help of aspirator and released within basin covered with muslin cloth and secured tightly. After 48 hours, larvae of each host species was removed gently without causing damage with the help of fine brush and was kept individually in petriplates (9 cm diameter). The life expectancy of various life stages of *Bracon* spp. reared on different hosts and reproductive data on fecundity, egg hatching (%), and sex ratio were estimated. On this basis the host preference of the larval ecto-parasitoid, *Bracon* spp. was worked out. Data on egg hatching (%), eclosion (%), viability (%), survivorship (%) and fecundity were analysed in Completely Randomized Block Design after appropriate transformation. Size of various stages of *Bracon* spp. was also measured with the help of trinocular microscope (Nicon, DS- Fi 1).

### 3.2.4 To study the biology of *Bracon hebetor* Say (Hymenoptera : Braconidae) on various lepidopteran larvae under laboratory conditions.

A study was conducted on the reproductive parameters of *B. hebetor* on six different hosts namely Rice meal moth, *Corcyra cephalonica* Stainton, brinjal shoot and fruit borer, *Leucinodes orbonalis* Guenee, okra shoot and fruit borer, *Earias vittella* Fab., lemon butterfly, *Papilio demoleus* Lin., diamond back moth, *Plutella xylostella* Linn.) and teak skeletonizer*, Eutectona macheralis,* Walker under laboratory conditions. Initial cultures of host larvae were collected from field and reared on their respective natural food to obtain healthy and uniform aged (fourth instar) larvae newly emerged one male and one female *B. hebetor* was placed in a glass jar (15cm x 9cm) covered with a piece of white muslin cloth over which one full grown larva reared on respective host was placed. After placing the larva it was covered with another piece of white muslin cloth of same size. Five replicates were used for each host species. After 24 h the parasitized larvae of each host species was removed gently with the help of a fine brush and was kept individually in plastic bowls (4.50cm x 3.50cm) for further studies on various biological parameters. Fecundity and percentage of hatchability were analyzed by using appropriate transformations. Data on egg hatching (%), eclosion (%), viability (%), survivorship (%) and fecundity were analysed in Completely Randomized Block Design after arc sine and square root transformation, respectively.

### 3.2.5 To construct the life table of *Bracon hebetor* on *Corcyra cephalonica* Stainton (Lepidoptera : Pyralidae).

#### 3.2.5.1 *Bracon hebetor*

The population of *B. hebetor* adults were used in this study. The parasitoids have been maintained in the laboratory with most rearing on *C. cephalonica***.**

**3.2.5.2 Host Insect Culture**

2.5 kg of grains (Jawar+Maize+Bajra) were kept in wooden cages (45cm× 30cm×15cm). The grains were sterilized in hot air oven for one hour at $100^0$C. After cooling the grains were grinded coarsely. 5 ml of 10% honey solution along with 5g of yeast and a pinch of Streptomycin were mixed in each container. Finally the containers were charged with 0.25cc (approximately 4750) eggs of *C. cephalonica.*

**3.2.5.3 Experiment**

Newly emerged adults of *B. hebetor* were paired (male and female) in small plastic container (100 ml). A small drop of honey was put in the container wall as food. A fully grown larva of *C. cephalonica* was released individually into each container and allowed the parasitoid to oviposit on the host larva for 24 hours. After parasitization, parasitized larvae were collected and placed individually into a petridish (90 mm in diameter). Every day the parasitoids were transferred to a new plastic container with their corresponding host larva. When the male was found to be dead, it was replaced by a male of similar age. Total number of daily laid eggs and longevity of female and male *B. hebetor* adults were recorded. The container containing eggs of the parasitoid was held further at the same condition, the developmental time of each stage was recorded. Data on mortality were recorded daily till all the adults died. The life table data obtained from daily observations of immature and adult stages. Experiment carried out at 25 $^0$C, 65.5% RH and replicated for five times.

**3.2.5.4 Life table construction**

The methods suggested by Patil *et al*., (2014), Chi and Liu (1985) and Sokal and Rohlf (1981) were used for constructing the life-tables. From 126 eggs the number of live and dead, were recorded daily and the following heads were used in the documentation of age-specific life-table.

**mx** : As the sex ratio was 1:1, the number of eggs obtained / female were divided by two to get the number of female birth (mx). The headings for the construction of the life fecundity tables proposed by Howe (1953) and Atwal and Bains (1974) were used in this study, *viz*.,

**x** = Pivotal age in days/ age at beginning of interval

**lx** = Survival of female at age ‘X’

**mx** = Age schedule for female births at age ‘X’/expected number of daughters produced at age ‘X’

**3.2.5.5 Net reproductive rate (Ro)/ Net replacement rate**

The values of ‘x’, ‘lx’ and ‘mx’ were calculated from the data given in life tables. The sum total of the products ‘lxmx’ is the net reproductive rate (Ro). The ‘Ro’ is the rate of multiplication of population in generation measured in terms of females produced per generation. The number of times a population would multiply per generation was calculated by the following formula, Ro = Σlxmx.

**3.2.5.6 Mean duration of generation (Tc)**

The appropriate value of generation time (Tc) *i.e.* the mean age of the mothers in a cohort at the birth of female offspring was calculated by using the following formula:

Tc = Σxlxmx/Ro

**3.2.5.7 Innate capacity for increase (rm)**

Total number of individuals survived and mean number of female offspring births were recorded at each age interval. From these data, the arbitrarily value of ‘rm (rc)’ was derived by the following formula:

rm = logeRo/Tc (number of progeny produced per unit time)

Tc = Mean generation time

T = logeRo/rm (T= mean of period over which progeny are produced)

**3.2.5.8 The finite rate of natural increase (λ)**

The number of females offspring per female per day i.e. finite rate of increase was determined as: λ= antilog $e^{rm}$ .

From this data, the weekly multiplication of the population was calculated. The hypothetical F2 females were also be worked out with the formula $(Ro)^2$.

**3.2.5.9 Life table for computing life expectancy of *Bracon hebetor* Say**

Life expectancy of the *Bracon hebetor* was worked out by using columns x, lx, dx, 100qx, Lx, Tx and ex. Where,

**x** = Pivotal age (days)

**lx** = Number of surviving at the beginning of age interval out of 100

**dx** = Number dying during 'x'

**100qx** = dx.100 /lx, Mortality rate per hundred alive at the beginning of age interval.

$Lx = \frac{\text{lx} + (\text{lx} + 1)}{2}$ Alive between x and x + 1 or $Lx = \frac{1}{2}(lx + lx + 1)$

**Tx** = Number of individual's life days beyond 'x' and

$$ex = \frac{Tx}{lx} \times 2$$

(where ex = expectation of life or mean life time remaining to those attaining age interval)

Expectation of further life Equations were formulated after processing the data in MS-Excel.

### 3.2.6 To study the viability of *Bracon hebetor* (Say) cocoons during storage as Bracocards.

*Bracon hebetor* was reared on Rice meal moth, *Corcyra cephalonica* Stainton at ordinary room temperature under laboratory conditions. The mouth of glass jar (15cm x 9cm) containing five pairs of newly emerged *B. hebetor* was covered with a piece of white muslin cloth over which five full grown larvae of *C. cephalonica* were placed. After placing the larvae on the mouth of glass jar it was again covered with another piece of white muslin cloth of same size.

#### 3.2.6 .1 Cold storage treatments

Cold storage experiments were carried out on the cocoons (pupal stage) of *B. hebetor*. Ten 24-hrs old pupae of *B. hebetor* were carefully removed with a camel hair brush from the hosts larvae and collected and stuck on glue coated black paper cords (6.5cm×4.5cm) to produce Bracocards.

Thirty Bracocards each having 10 cocoons was prepared and five replicates were randomly allocated to the cold storage treatments. Treatments consisted of combinations of three temperature levels (4, 9 and 12 °C) with six cold storage times (One to six weeks). There was also a control group (without cold storage). Cold conditions were provided by temperature controlled rearing chambers. The control group was kept at the same rearing conditions (27 ± 1 °C, 60 ± 5% RH). Once the storage period was over, each treated group was brought back to the rearing chamber at standard conditions. The effect of temperature and time of cold storage on the parasitoid emergence was evaluated by measuring the percentage of emerged adults, sex ratio and adult longevity.

### 3.2.7 To study the management of diamonback moth, *Plutella xylostella* L. on cabbage crop by release of *Bracon hebetor* Say under field conditions.

A field experiment was conducted during February, 2017 at the Horticulture Instructional Farm, Pt. Kishorilal Shukla College of Horticulture and Research Station, Rajnandgaon (Chhattisgarh) with seven treatments, replicated thrice in Randomized Block Design (Fig. 3.1). Before release of bracocard, larval population of diamondback moth was recorded and the post release observations were recorded after 2, 7, 12, 15 and 20 days (Table 3.1). Twenty one plants of cabbage were randomly selected, netted and the treatments (Table 3.2) were applied on the onset of maximum pest incidence. The number of healthy and parasitized larva was counted and percentage of parasitization was worked out from the recorded observations. Parasitized larvae was brought back to the laboratory and looked for the emergence of parasitoid species.

**Table 3.1 Experimental Details**

| | |
|---|---|
| (a) Design | RBD |
| (b) Treatment | 07 |
| (c) Replication | 03 |
| (d) Planting distance | 60×30 cm |
| (e) Replication spacing | 2 meter |
| (f) Plot spacing | 2 meter |
| (g) Cage size | 2×2 meter |
| (h) Experimental Area | 100 x 10 (L x W) = 1000 $m^2$ |
| (i) Crop | Cabbage (*Brassica olerecia* var. *capitata*) |
| (j) Variety | Golden Acre |
| (k) Date of Bracocard release | 17/02/2017 |
| (l) Observation | (1) Pre-treatment |
| | (2) Post treatment (2, 7, 12, 15 and 20 Day after release) |

**Table 3.2 Treatments detail.**

| S.N. | Treatments |
| --- | --- |
| 1. | Bracocard (4 cocoon) |
| 2. | Bracocard (8 cocoon) |
| 3. | Bracocard (10 cocoon) |
| 4. | Bracocard (15 cocoon) |
| 5. | Bracocard (20 cocoon) |
| 6. | Covered plant without cocoon |
| 7. | Control |

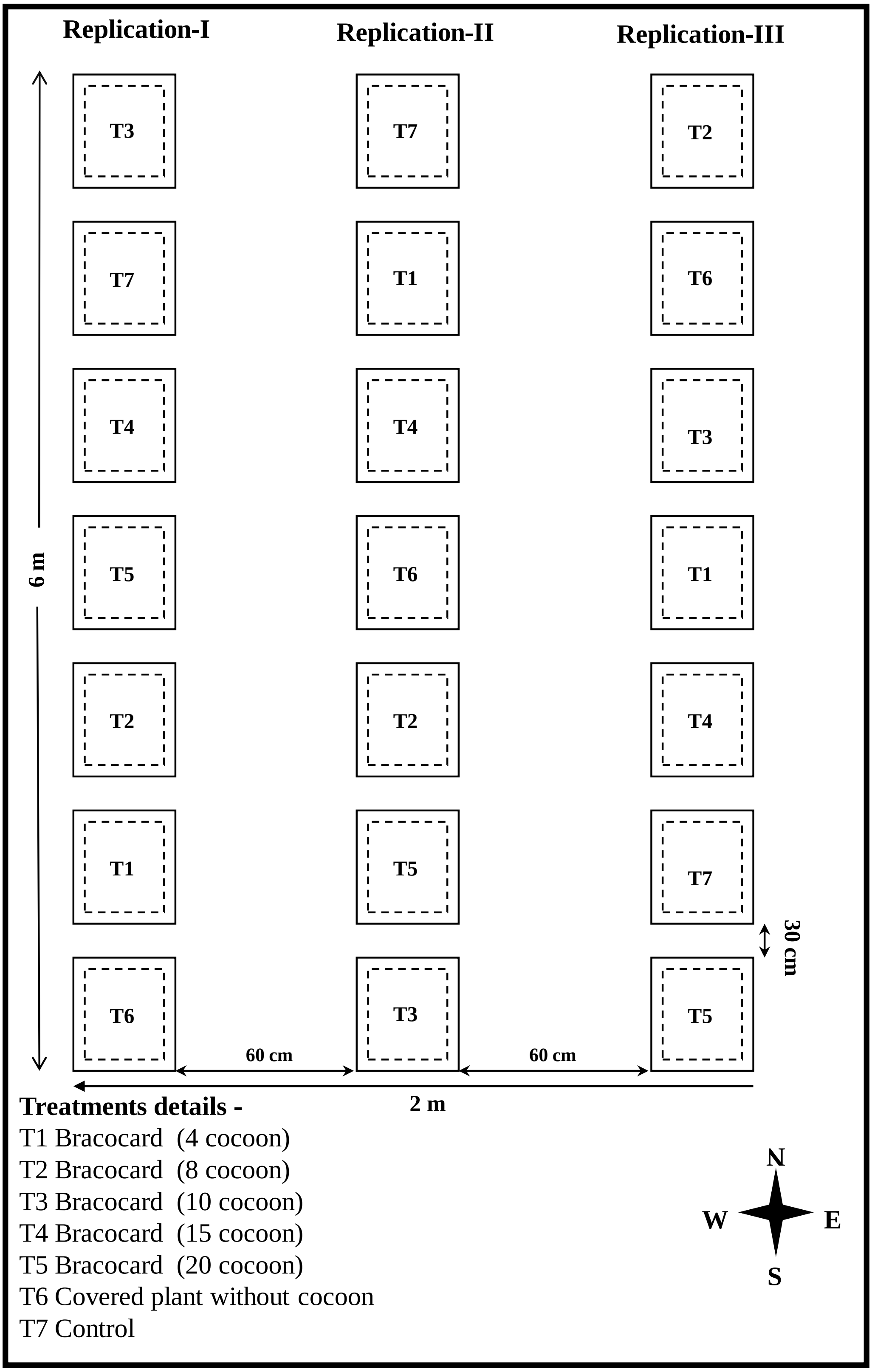



**Fig. 3.1 Layout of experimental field and treatments details.**

## CHAPTER- IV

# RESULTS AND DISCUSSION

The present piece of investigation **"Studies on the host variability and ovipositional behaviour of larval ecto-parasitoid, *Bracon* spp. (Hymenoptera : Braconidae) at Raipur, Chhattisgarh"** was conducted during 2015-16 and 2016-17 at the Biocontrol laboratory, Department of Entomology, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya Raipur (C.G.)

The results of the study are presented and discussed under the following heads:-

### 4.1 To record the naturally available species of *Bracon* on few cereals, legumes, vegetables and fruits at Raipur, Chhattisgarh ecosystem.

Survey work was conducted during *kharif*-*rabi*, 2015-16 and 2016-2017 at different crop ecosystem at Raipur, Chhattisgarh. Rice meal moth, *Corcyra cephalonica* was used to trap Braconids on cereals like paddy and maize, legumes like pigeon pea and chickpea, vegetables like brinjal, tomato, cabbage and okra and fruits like ber, guava, sapota and mango ecosystem. Different *Bracon* spp. were collected at fortnightly interval on randomly selected five plants of each crop (Fig. 4.2 and 4.3). Collected specimen of Braconid and other parasitiods were identified from NBAIR, Bengaluru.

During the course of study, eighteen species of *Bracon* were noticed on various crop ecosystem. Findings on the natural enemies fauna are as mentioned below:

### 4.1.1 Record of naturally existing species of *Bracon* and other parasitoids on cereals

#### 4.1.1.1 Paddy crop ecosystem

During *kharif* 2015-16 and 2016-2017 six parasitoids species were recorded on paddy ecosystem. *Cotesia flavipes* (Cameron) and *Elasmus* sp. (Elasmidae) were first recorded during 38$^{th}$ and 40$^{th}$ SMW in the year 2015. *Bracon* spp. was found during 31$^{st}$ SMW and *Cotesia flavipes* was recorded during 44$^{th}$ SMW in the year 2016. Another unidentified NE (3) was also collected during 35$^{th}$ SMW. Most of the parasitoids were noticed at later stage of the crop when pest population was maximum (Table 4.1).

The above findings are in line with the findings of Borah and Saharia (1989) who also reported *Bracon* sp. as the dominant parasitoid of *Cnaphalocrocis medinalis* under rice crop ecosystem and population of Braconids increased with the increase in pest numbers, and peaked either coincidentally or after the peak incidence of the pyralid. Sathe (2004) also recorded natural parasitization of *Chilo partellus* by *Cotesia flavipes.*

**4.1.1.2 Maize crop ecosystem**

First appearance of the parasitoid was observed in third week of August. *Cotesia flavipes* (Cameron), unidentified NE (12) and unidentified NE (9) was observed in the 33$^{rd}$, 40$^{th}$ and 43$^{rd}$ SMW, respectively during the first year. During the second year of survey work only *Bracon* spp was found in Maize crop ecosystem (Table 4.1).

Similarly, Maini and Burgio (1990) had recorded *Bracon hebetor* as a larval parasitoid of *Ostrinia nubilalis* under maize crop ecosystem in Emilia Romagna, Italy. Noori (1994) also found natural parasitization of *Heliothis* by *B. hebetor* during mid-September in maize field in Iran. Ebenebe *et al*. (2001) collected *Cotesia sesamiae* and *B. brevicornis* as larval parasitoid of *Chilo partellus* from the field of maize and also noticed that the activities of natural enemies increased only towards the end of the growing season. Politz, *et al*. (2007) also found occurrence of *B. brevicornis* as a parasitoid of European corn borer (*Ostrinia nubilalis*) in Saxony (Germany).

Similar findings were reported by Sertkaya *et al*. (2005) who observed the natural parasitization of *Sesamia nonagrioides* by the larval parasitoids Braconid, *Cotesia ruficrus*, *Habrobracon hebetor* (*B. hebetor*).

According to Bayram *et al*. (2007) *Habrobracon hebetor* (Say) (Hymenoptera: Braconidae) caused 1.1% parasitism in Mediterranean corn stalk borer, *Sesamia nonagrioides* Lefebvre (Lepidoptera: Noctuidae), under field conditions in Turkey during the first year of the study.

**Table 4.1. Record of naturally available species of *Bracon* and other parasitoids on cereals at Raipur, Chhattisgarh during 2015-16 to 2016-17.**

| SMW | Date of survey | Paddy | | SMW | Date of survey | Maize | |
|---|---|---|---|---|---|---|---|
| | | 2015 | 2016 | | | 2015 | 2016 |
| 31 | 31/07/2015 | | *Bracon* spp. | 31 | 03/08/2015 | | |
| 33 | 16/08/2015 | | | 33 | 19/08/2015 | *Cotesia flavipes* (Cameron) | |
| 35 | 01/09/2015 | | Unidentified NE 3 | 36 | 04/09/2015 | | |
| 38 | 17/09/2015 | *Cotesia flavipes* (Cameron) | | 38 | 20/09/2015 | | |
| 40 | 03/10/2015 | *Elasmus* sp. (Elasmidae) | | 40 | 06/10/2015 | Unidentified NE 12 | *Bracon* spp |
| 42 | 19/10/2015 | | *Bracon* spp. | 43 | 22/10/2015 | Unidentified NE 9 | |
| 44 | 04/11/2015 | | *Cotesia flavipes* (Cameron) | 45 | 07/11/2015 | | |

**Table 4.2 Record of naturally available species of *Bracon* and other parasitoids on legumes at Raipur, Chhattisgarh during 2015-16 to 2016-17.**

| SMW | Date of survey | Pigeon pea | | SMW | Date of survey | Chickpea | |
|---|---|---|---|---|---|---|---|
| | | 2015 | 2016 | | | 2015 | 2016 |
| 34 | 25/08/2015 | | | 01 | 06/01/2015 | | |
| 37 | 10/09/2015 | | | 04 | 22/01/2015 | | |
| 39 | 26/09/2015 | | | 06 | 07/02/2015 | *Bracon hebetor* Say | |
| 41 | 12/10/2015 | | | 08 | 23/02/2015 | | |
| 43 | 28/10/2015 | | | 10 | 11/03/2015 | | |
| 46 | 13/11/2015 | *Bracon hebetor* Say | | 13 | 27/03/2015 | | |
| 48 | 29/11/2015 | Unidentified NE 11 | | | | | |
| 50 | 15/12/2015 | | Unidentified NE 8 | | | | |
| 52 | 31/12/2015 | | | | | | |
| 03 | 16/01/2016 | | | | | | |
| 05 | 01/02/2016 | | | | | | |
| 07 | 17/02/2016 | | *Cotesia flavipes* Cameron | | | | |

Maize field

Pigeon pea field

Chick pea field

Brinjal field

Tomato field

**Fig.4.2 Survey at different crop ecosystem at Raipur, Chhattisgarh during 2015-16 to 2016-17.**

### 4.1.2 Record of naturally existing species of *Bracon* and other parasitoids on legumes

#### 4.1.2.1 Pigeon pea crop ecosystem

During the first year of survey (2015-16) *Bracon hebetor* was collected in the second week of November. Unidentified NE (11) was also recorded during 48$^{th}$ SMW. In the second year 2016-17 unidentified NE (8) and *Cotesia flavipes* were recorded during 50$^{th}$ and 07$^{th}$ SMW (Table 4.2).

Sathe (2004) found the activity of Braconids under pigeon pea crop ecosystem to parasitize *Exelastis atomosa* larvae which is in agreement with the present finding.

#### 4.1.2 .2 Chickpea crop ecosystem

During *rabi* 2015-16 *Bracon hebetor* was recorded in the second week of December however, no parasitoids were observed during the survey of 2016-17 (Table 4.2).

Similarly, Noori (1994) had also found natural parasitization of *Heliothis* by *B. hebetor* in early June in chickpea fields and noticed parasitism rates increased as temperatures increased. Sathe (2004) observed *Cotesia ruficrus* attacked 8% of the larvae of *Helicoverpa armigera*.

### 4.1.3 Record of naturally existing species of *Bracon* and other parasitoids on vegetables crops

#### 4.1.3.1 Brinjal crop ecosystem

During both years, *Cotesia flavipes* was most abundantly present in 2015-16 it was first observed during 36$^{th}$ SMW. Unidentified NE (1) and unidentified NE (7) was also recorded during 43$^{rd}$ and 45$^{th}$ SMW respectively (Table 4.3).

Yasodha and Natarajan (2009) also recorded *B. hebetor* Say as a larval parasitoid of *Leucinodes orbonalis* under field condition which is in support of the present findings.

**Table 4.3 Record of naturally available species of *Bracon* and other parasitoids on vegetable crops at Raipur, Chhattisgarh during 2015-16 to 2016-17.**

| SMW | Date of survey | Brinjal | | SMW | Date of survey | Tomato | |
|---|---|---|---|---|---|---|---|
| | | 2015 | 2016 | | | 2015 | 2016 |
| 31 | 03/08/2015 | | | 03 | 18/01/2015 | | |
| 33 | 19/08/2015 | | | 05 | 03/02/2015 | | |
| 36 | 04/09/2015 | *Cotesia flavipes* Cameron | | 08 | 19/02/2015 | *Bracon* spp. | |
| 38 | 20/09/2015 | | | 10 | 07/03/2015 | | |
| 40 | 06/10/2015 | | | 12 | 23/03/2015 | | |
| 43 | 22/10/2015 | Unidentified NE 1 | | 14 | 08/04/2015 | | |
| 45 | 07/11/2015 | Unidentified NE 7 | | | | | |
| 47 | 23/11/2015 | | *Cotesia flavipes* Cameron | | | | |

| SMW | Date of survey | Cabbage | | SMW | Date of survey | Okra | |
|---|---|---|---|---|---|---|---|
| | | 2015 | 2016 | | | 2015 | 2016 |
| 50 | 13/12/2015 | *Bracon brevicornis* (Wesmael) | | 31 | 05/08/2015 | | |
| 52 | 29/12/2015 | *Cotesia flavipes* Cameron | *Bracon* spp | 34 | 21/08/2015 | | |
| 02 | 14/01/2016 | *Cotesia flavipes* Cameron | | 36 | 06/09/2015 | *Bracon* spp. | |
| 05 | 30/01/2016 | | *Bracon* spp | 38 | 22/09/2015 | | |
| 07 | 15/02/2016 | *Bracon* spp. | | 41 | 08/10/2015 | | *Bracon hebetor* Say |
| 09 | 02/03/2016 | | *Cotesia flavipes* Cameron | 43 | 24/10/2015 | *Bracon* spp. | |
| | | | | 45 | 09/11/2015 | | |

Cabbage field

Okra field

Guava

Sapota

Mango

**Fig.4.3 Survey at different crop ecosystem at Raipur, Chhattisgarh during 2015-16 to 2016-17.**

#### 4.1.3.2 Tomato crop ecosystem

In this survey only one parasitoid, *Bracon* sp. was found during 8$^{th}$ SMW in both the years 2015-16 and 2016-17 (Table 4.3).

Similar reports of natural parasitization of *Heliothis* by *B. hebetor* during mid-September in tomato field have been reported by Noori (1994). Voloshenko and Khachumov (2000) also used successfully *H. hebetor* for the control of *Helicoverpa armigera* in tomato fields.

#### 4.1.3.3 Cabbage crop ecosystem

Highest number (7) of parasitoids was recorded in cabbage crop ecosystem during both the years of survey. First appearance of the parasitoid was observed during second week of December 2015. *Bracon brevicornis* was recorded for the first time in cabbage crop ecosystem. Among other parasitoids, *Cotesia flavipes* was recorded during 52$^{nd}$ and 2$^{nd}$ SMW during the year 2015-16. *Bracon* spp. was also observed during third week of February (2016). During the second season of the survey in 2016-17 *Bracon* sp. was recorded during 52$^{nd}$ and 05$^{th}$ SMW. *C. flavipes* was observed during the first week of March and recorded as most dominant parasitoid (Table 4.3).

Kfir (1997) also reported *Bracon brevicornis* and *Cotesia plutellae* as larval parasitoids of *Plutella xylostella* on cabbage field from South Africa. Sathe (2004) found natural parasitization of the larvae of *Pieris brassicae* with 4 % parasitization by *Cotesia glomerata* under field condition. Similarly Afiunizadeh and Karimzadeh (2015) reported naturally occurring parasitization on diamondback moth in field which included Braconids, *Cotesia vestalis* (Kurdjumov), *Bracon hebetor* Say and *Apanteles* sp. These findings illustrate the important role of parasitoids for sustainable management of diamondback moth which are in agreement with the present findings.

### 4.1.3.4 Okra crop ecosystem

Braconids made their first appearance in the first week of September and second appearance was noticed during the fourth week of October, 2015. In the survey year 2016, only *Bracon hebetor* Say was collected during the second week of October (Table 4.3).

Similarly, Sathe (2004) found that *B. brevicornis* parasitized the larvae of *Earias fabia* (*E. vittella*) (18%) and *Earias insulana* (7.5%) under okra field. Ahemaiti *et al*. (2006) also recorded frequent species of Braconid in cotton field in China and reported to be the most frequent and dominant species of larval parasitoid infesting *Helicoverpa armigera* in the field. Similarly, Borkar and Sarode (2013) observed parasitization of *Helicoverpa armigera* (Hubner) by Braconids in Malvaceaous crops.

### 4.1.4 Record of naturally existing species of *Bracon* and other parasitoids on fruits crops

### 4.1.4.1 Ber ecosystem

First appearance of the parasitoid was observed during the first week of December. Two natural enemies namely unidentified NE (2) and unidentified NE (10) were recorded during 49$^{th}$ SMW and 04$^{th}$ SMW respectively in the year 2015-16 (Table 4.4).

### 4.1.4.2 Guava ecosystem

Only one species of parasitoid (unidentified NE 6) was recorded from the survey year 2015-16 and 2016-17 (Table 4.4).

### 4.1.4.3 Sapota ecosystem

Appearance of parasitoids started from the 36$^{th}$ SMW to 20$^{th}$ SMW during both the survey years. *Goniozus* sp was recorded as a most dominant parasitoid during 36$^{th}$, 50$^{th}$ and 20$^{th}$ SMW of the year 2015-16. *Cotesia flavipes* was the only parasitoid recorded during the second to fourth week of October 2016-17 (Table 4.5).

Ghirtlahre *et al*. (2014) previously reported Braconids parasitizing the larvae of sapota leaf webber, *Nephopteryx eugraphella* Ragonot and marble moth, *Celypha*

**Table 4.4 Record of naturally available species of *Bracon* and other parasitoids on fruit crops at Raipur, Chhattisgarh during 2015-16 to 2016-17.**

| SMW | Date of survey | Ber | | SMW | Date of survey | Guava | |
|---|---|---|---|---|---|---|---|
| | | 2015 | 2016 | | | 2015 | 2016 |
| 47 | 21/11/2015 | | | 44 | 03/11/2015 | | |
| 49 | 07/12/2015 | Unidentified NE 2 | | 47 | 19/11/2015 | | |
| 51 | 23/12/2015 | | | 49 | 05/12/2015 | | |
| 02 | 08/01/2016 | | | 51 | 21/12/2015 | | |
| 04 | 24/01/2016 | | Unidentified NE 10 | 01 | 06/01/2016 | | |
| 06 | 09/02/2016 | | | 04 | 22/01/2016 | | Unidentified NE 6 |
| | | | | 06 | 07/02/2016 | | |

*woodiana* however, *Goniozus* sp attacked on sapota bud worm, *Aarsia* sp. in Bilaspur, Chhattisgarh which was confirmed in the present investigation. Similarly, Jayanthi and Verghese (2007) also reported parasitoids on sapota seed borer, *Trymalitis margarias* Meyrick in Karnataka, India, in which two species of parasitoids were observed parasitizing sapota seed borer, namely, *Bracon* sp. and *Eurytoma braconidis.*

**4.1.4.4 Mango ecosystem**

Occurrence of parasitoids initiated from fourth week of October (43rd SMW) of which *Cotesia flavipes* was the dominant species recorded during 43rd and 52nd SMW. Two unidentified NE 4 and NE 5 were observed in the year 2015-16 and 2016-17, respectively (Table 4.5).

Diaconu *et al*. (2000) recorded ectoparasitoid Braconids on certain species of leaf rollers (Lepidoptera: Tortricidae) of fruit trees *viz., Malus, Pyrus, Prunus* and *Cerasus.* However, Carlos *et al.,* (2002) found that March and June were the months of highest occurrence of Braconids in Romania under fruit tree ecosystem.

Thus, from the present piece of investigation, it can be concluded that highest number of parasitoids were recorded in paddy, maize and pigeon pea with four species of parasitoids namely *Bracon* sp., *Bracon hebetor* Say, *Cotesia flavipes* Cameron and twelve unknown species (Table 4.6). *Bracon brevicornis* and *Goniozus* spp. were recorded for the first time in cabbage and sapota crop ecosystem, respectively. The phenomenon of co-occurrence of two or more parasitoids was observed in many cases. All parasitoid species collected, are recorded for the first time in Raipur, Chhattisgarh (Table 1). Eighteen species of parasitoid wasp *viz., Cotesia flavipes, Elasmus* sp., *Bracon* spp, *Bracon hebetor* Say, *Bracon brevicornis* (Wesmael), *Goniozus* sp. and twelve species have already been sent to NBAIR, Bengaluru for identification and the results are awaited. The most dominant parasitoids in decreasing order are *Cotesia flavipes* (32%), *Bracon* sp.(20%), *Bracon hebetor* (7%), *Goniozus* sp. (7%) and *Bracon brevicornis* (2%) (Table 4.7 and Fig. 4.1).

These results contribute to the knowledge of the entomological fauna occurring in the plain regions of Chhattisgarh. Our findings indicated that, the local species of

**Table 4.5 Record of naturally available species of *Bracon* and other parasitoids on fruit crops at Raipur, Chhattisgarh during 2015-16 to 2016-17.**

| SMW | Date of survey | Sapota | | SMW | Date of survey | Mango | |
|---|---|---|---|---|---|---|---|
| | | 2015 | 2016 | | | 2015 | 2016 |
| 32 | 06/08/2015 | | | 34 | 21/08/2015 | | |
| 34 | 22/08/2015 | | | 36 | 06/09/2015 | | |
| 36 | 07/09/2015 | *Goniozus* sp (Bethylidae) | | 38 | 22/09/2015 | | |
| 38 | 23/09/2015 | | | 41 | 08/10/2015 | | |
| 41 | 09/10/2015 | | *Cotesia flavipes* Cameron | 43 | 24/10/2015 | *Cotesia flavipes* Cameron | |
| 43 | 25/10/2015 | | *Cotesia flavipes* Cameron | 45 | 09/11/2015 | | |
| 45 | 10/11/2015 | | | 47 | 25/11/2015 | | |
| 48 | 26/11/2015 | | | 50 | 11/12/2015 | | |
| 50 | 12/12/2015 | *Goniozus* sp (Bethylidae) | | 52 | 27/12/2015 | Unidentified NE 4 | *Cotesia flavipes* Cameron |
| 52 | 28/12/2015 | | | 02 | 12/01/2016 | | |
| 02 | 13/01/2016 | | | 04 | 28/01/2016 | | |
| 05 | 29/01/2016 | | | 07 | 13/02/2016 | | |
| 07 | 14/02/2016 | | | 09 | 29/02/2016 | | |
| 09 | 01/03/2016 | | | 11 | 16/03/2016 | | |
| 11 | 17/03/2016 | | | 13 | 01/04/2016 | | |
| 14 | 02/04/2016 | | | 16 | 17/04/2016 | | Unidentified NE 5 |
| 16 | 18/04/2016 | | | 18 | 03/05/2016 | | |
| 20 | 04/05/2016 | *Goniozus* sp (Bethylidae) | | | | | |
| 20 | 20/05/2016 | | | | | | |

**Table 4. 6 Specimen of Braconidae (Hymenoptera) collected from different crop ecosystem at Raipur, Chhattisgarh during 2015-16 and 2016-17.**

| S.N. | Paddy | |
|---|---|---|
| 1 | | *Cotesia flavipes* (Cameron) |
| 2 | | *Elasmus* sp. (Elasmidae) |
| 3 | | *Bracon* spp. |
| 4 | | Unidentified NE 3 |
| 5 | | *Bracon* spp |
| 6 | | *Cotesia flavipes* (Cameron) |
| | **Maize** | |
| 1 | | *Cotesia flavipes* (Cameron) |
| 2 | | Unidentified NE 12 |
| 3 | | Unidentified NE 9 |
| 4 | | *Bracon* spp |
| | **Pigeon pea** | |
| 1 | | *Bracon hebetor* Say |
| 2 | | Unidentified NE 11 |
| 3 | | Unidentified NE 8 |
| 4 | | *Cotesia flavipes* Cameron |
| | **Chickpea 1** | |
| 1 | | *Bracon hebetor* Say |
| | **Brinjal** | |
| 1 | | *Cotesia flavipes* Cameron |
| 2 | | Unidentified NE 1 |
| 3 | | Unidentified NE 7 |
| 4 | | *Cotesia flavipes* Cameron |

| S. N. | Tomato | *Bracon* spp. |
|---|---|---|
| | **Cabbage** | |
| 1 | | *Bracon brevicornis* (Wesmael) |
| 2 | | *Cotesia flavipes* Cameron |
| 3 | | *Cotesia flavipes* Cameron |
| 4 | | *Bracon* spp. |
| 5 | | *Bracon* spp |
| 6 | | *Bracon* spp |
| 7 | | *Cotesia flavipes* Cameron |
| | **Okra** | |
| 1 | | *Bracon* spp. |
| 2 | | *Bracon* spp. |
| 3 | | *Bracon hebetor* Say |
| | **Ber** | |
| 1 | | Unidentified NE 2 |
| 2 | | Unidentified NE 10 |
| | **Guava** | |
| | | Unidentified NE 6 |
| | **Sapota** | |
| 1 | | *Goniozus* sp (Bethylidae) |
| 2 | | *Goniozus* sp (Bethylidae) |
| 3 | | *Goniozus* sp (Bethylidae) |
| 4 | | *Cotesia flavipes* Cameron |
| 5 | | *Cotesia flavipes* Cameron |
| | **Mango** | |
| 1 | | *Cotesia flavipes* Cameron |
| 2 | | Unidentified NE 4 |
| 3 | | *Cotesia flavipes* Cameron |
| 4 | | Unidentified NE 5 |

**Table 4. 7 Specimen of Braconidae and other families of Hymenoptera collected from different crop ecosystem at Raipur, Chhattisgarh from 2015-16 to 2016-17.**

| Taxonomic group | Frequency | Percentage |
|---|---|---|
| *Cotesia flavipes* | 13 | 32 |
| *Bracon* spp | 8 | 20 |
| *Bracon hebetor* Say | 3 | 10 |
| *Goniozus* sp | 3 | 10 |
| *Elasmus* sp. | 1 | 2 |
| *Bracon brevicornis* (Wesmael) | 1 | 2 |
| Unidentified NE 1 | 1 | 2 |
| Unidentified NE 2 | 1 | 2 |
| Unidentified NE 3 | 1 | 2 |
| Unidentified NE 4 | 1 | 2 |
| Unidentified NE 5 | 1 | 2 |
| Unidentified NE 6 | 1 | 2 |
| Unidentified NE 7 | 1 | 2 |
| Unidentified NE 8 | 1 | 2 |
| Unidentified NE 9 | 1 | 2 |
| Unidentified NE 10 | 1 | 2 |
| Unidentified NE 11 | 1 | 2 |
| Unidentified NE 12 | 1 | 2 |
| **Total** | **41** | **100** |

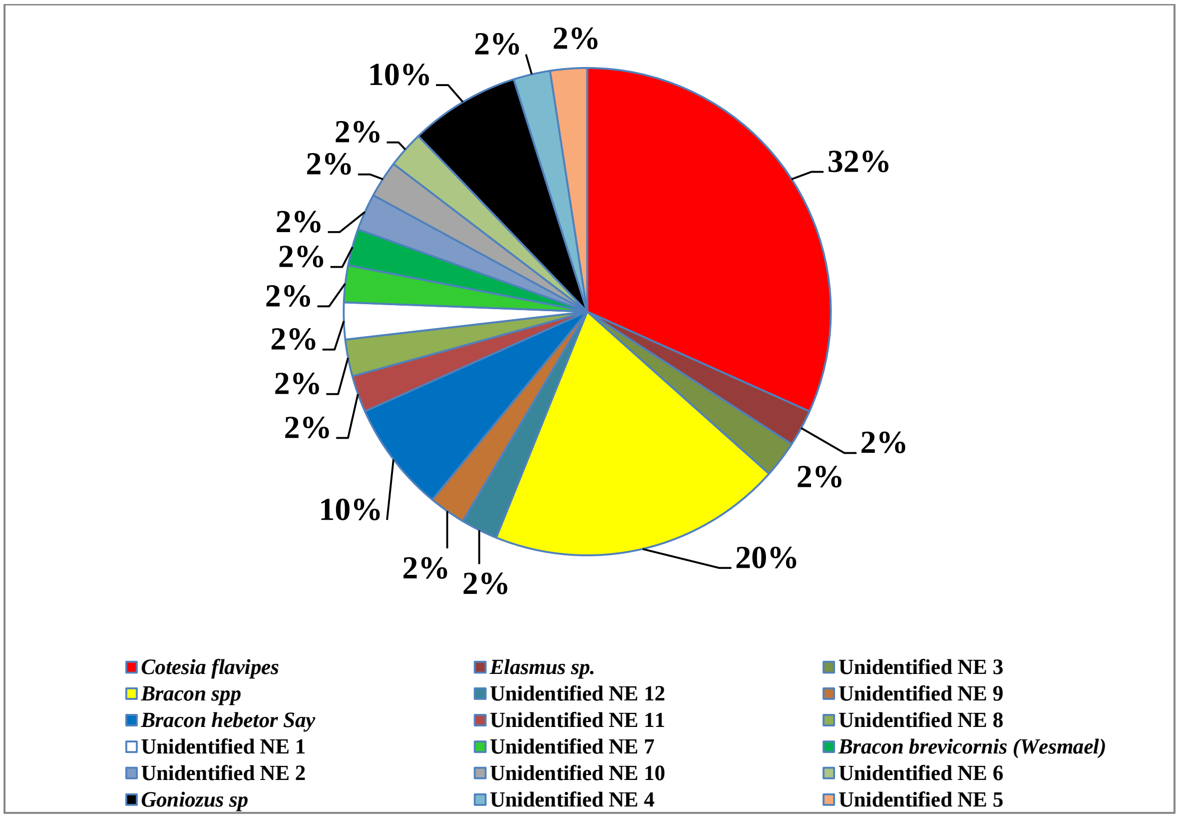



**Fig.4.1 Specimen of Braconidae and other families of Hymenoptera collected from different crop ecosystem at Raipur, Chhattisgarh from 2015-16 to 2016-17.**

Braconids existing in all crop ecosystem can play an important role in sustainable management of crop pests.

## 4.2 Preference of *Bracon* spp. on *Helicoverpa armigera* Hub. feeding on different hosts.

*Bracon hebetor* Say mated frequently and its females attacked and oviposited on the fourth instar larvae of *Helicoverpa armigera* Hub reared on different natural food *viz*., chick pea, pea, pigeon pea, okra and tomato (Fig. 4.7). Ovipositing females were found to locate their hosts probably via semiochemicals produced in the mandibular gland of the host larvae (Shonouda and Nasr, 1998). Once the host was located, the female *B. hebetor* injected venom, which resulted in complete paralysis of host larvae within 15 minutes also reported by Hagstrum and Smittle (1978). The venom blocks neuromuscular transmission at a presynaptic site and apparently has no effect on heartbeat or midgut function (Hagstrum and Smittle, 1978). After the host was paralyzed, the female oviposited, usually placing a clutch of several eggs on the ventral surface of the host or on the side that was in contact with the substrate. The morphological and developmental periods of each life stages of *B. hebetor* observed in the present studies are shown in Table 1 and 2.

### 4.2.1 Eggs

Freshly laid eggs were creamy white in colour and became translucent later. The deposited eggs were spindle shaped slightly curved, hyaline colourless and loosely attached to the surface of the host body (Fig. 4.9). The incubation period of *Bracon* sp. was statistically non significant differentiated in all host larvae. The incubation period of egg was highest on pigeon pea reared larvae with 1.70 days and lowest incubation period of egg was recorded in pea and okra reared larvae with 1.30 days (Table 4.8). Highest egg hatching percentage (91.0%) was registered (4.10) when it was reared on the larvae fed pigeon pea. Significantly highest fecundity 71.60/female was registered in case of pigeon pea followed by tomato, okra and pea fed *H. armigera* larvae (Fig. 4.5). On the other hand, significantly least number of eggs per female (45.80) were recorded from chick pea reared larvae (Table 4.10). Survivability of eggs in all the

**Table 4. 8 Development time (days) of different life-stages of *B. hebetor* reared on *Helicoverpa armigera* Hub. feeding on different hosts.**

| S/N | Host species | Egg | Larva | Pre-pupa | Pupa | Adult | | Female | | | Total life cycle | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Male | Female | Pre-oviposition | Oviposition | Post -oviposition | Male | Female |
| **1** | **Chick pea** | 1.50 | 3.90a | 0.90a | 5.40a | 4.10 | 5.60c | 0.60a | 3.40b | 1.60 | 15.80 | 17.30 |
| **2** | **Pea** | 1.30 | 3.70a | 0.61b | 4.50b | 4.70 | 6.95ab | 0.61a | 5.30a | 1.04 | 14.81 | 17.06 |
| **3** | **Pigeon pea** | 1.70 | 3.60a | 0.60b | 4.30b | 5.20 | 7.90a | 0.65a | 6.30a | 1.85 | 15.40 | 18.10 |
| **4** | **Okra** | 1.30 | 4.10ab | 0.55b | 4.35b | 5.40 | 7.50ab | 0.61a | 5.40a | 1.49 | 15.70 | 17.80 |
| **5** | **Tomato** | 1.45 | 4.60a | 0.51b | 4.70ab | 4.50 | 6.80b | 0.41b | 5.40a | 0.99 | 15.76 | 18.06 |
| | **SEm ±** | **0.16** | **0.19** | **0.06** | **0.21** | **0.29** | **0.30** | **0.05** | **0.36** | **0.24** | **0.36** | **0.38** |
| | **CD at 5%** | **NS** | **0.66** | **0.18** | **0.70** | **NS** | **1.03** | **0.17** | **1.27** | **NS** | **NS** | **NS** |
| | **C. V. (%)** | **27.58** | **12.68** | **22.13** | **11.53** | **16.20** | **11.26** | **23.75** | **18.73** | **52.70** | **5.94** | **5.95** |

NS = Not significant.

Same letter in a column are not significantly different.

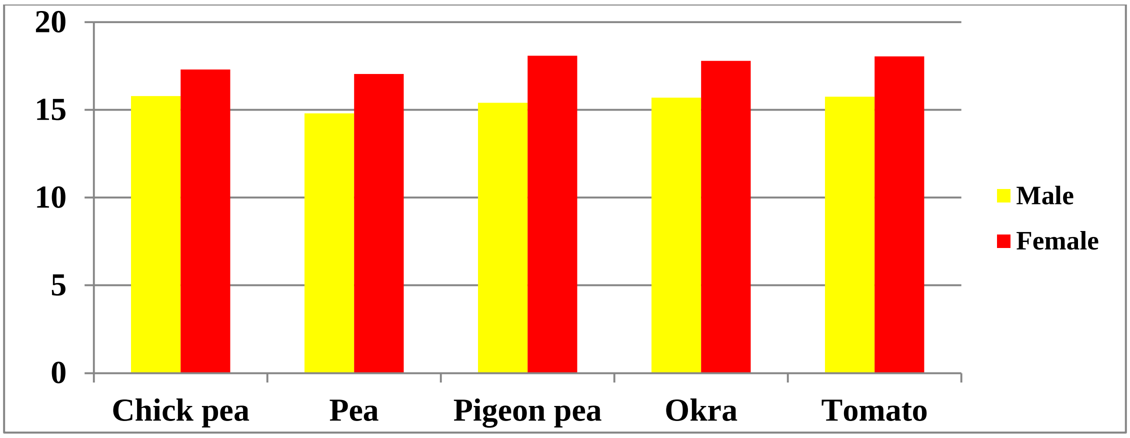



**Fig. 4.4 Total developmental period of male and female (Days) *B. hebetor* reared on *H. armigera* Hub. fed on different hosts**

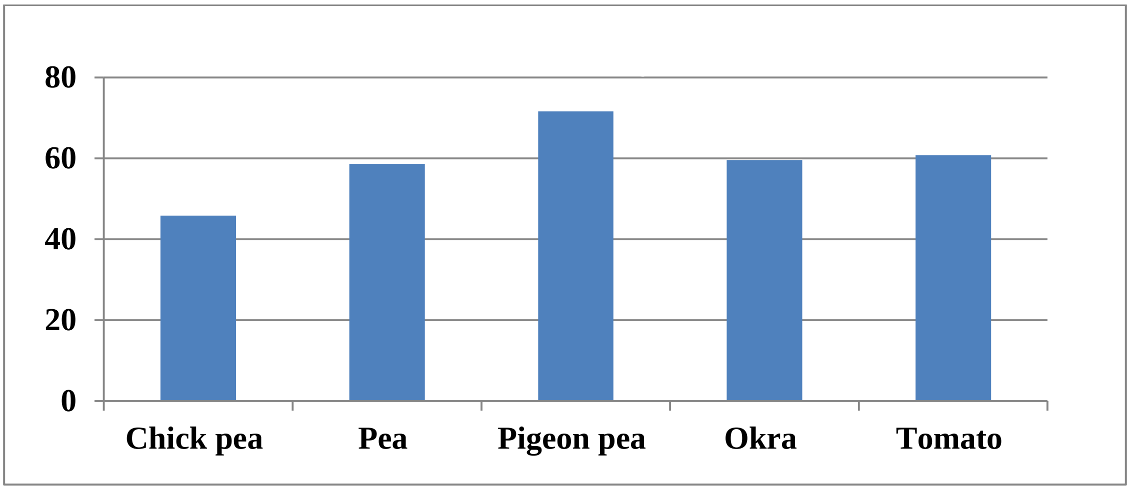



**Fig.4.5 Fecundity of *B. hebetor* reared on *H. armigera* Hub. fed on different hosts**

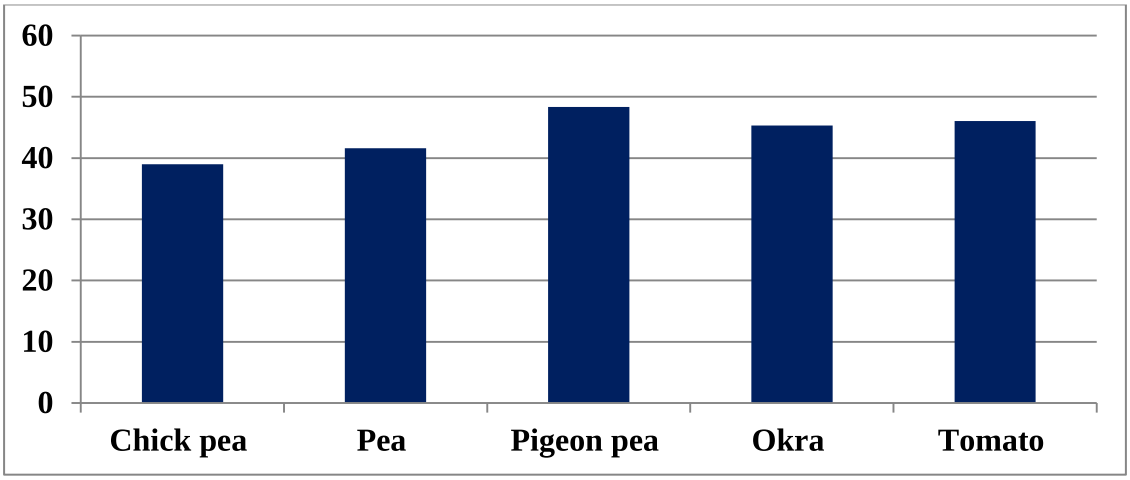



**Fig. 4.6 Per cent survivability from egg-adult of *B. hebetor* on *H. armigera* Hub. fed on different hosts**

***H. armigera*** **Rearing on chick pea**

***H. armigera*** **Rearing on pea**

***H. armigera*** **Rearing on pigeon pea**

***H. armigera*** **Rearing on okra**

***H. armigera*** **Rearing on Tomato**

**Fig.4.7** ***Helicoverpa armigera*** **Hub. rearing on different hosts.**

treatments was statistically at par and non significant. However, highest survivability of eggs was found in tomato reared larvae and least was observed in chick pea reared larvae (Table.4.11and Fig. 4.6).

**4.2.2 Larvae**

The mature larvae of *B. hebetor* were creamy white in colour and apodous (Fig. 4.9). The minimum and maximum length of larvae were 2.86 and 3.74 mm in chick pea and pigeon pea reared larvae, respectively. Similarly, minimum and maximum breadth of larva was also recorded in chick pea and pigeon pea reared larvae, of 1.03 and 1.33 mm respectively (Table 4.9). The minimum larval duration of 3.60 days was recorded in pigeon pea reared larvae however, maximum larval duration was recorded in tomato reared larvae of 4.60 days (Table 4.8). Survivability of larvae was statistically non significant in all the treatments. Highest survivability (78.33 %) of larvae was found in pigeon pea and least (71.13%) was registered from okra reared larvae.

**4.2.3 Pupae**

Pupation was found to take place outside the host body within a white coloured cocoon (Fig.4.9). Pupae were attached to one another by silken threads. The mature pupae were dark brown and exarate. The maximum length of pupal cocoon was recorded on pigeon pea reared larvae with 4.05 mm and minimum in chick pea reared larvae measuring 3.55 mm. The minimum and maximum breadth of pupal cocoon was 1.51 and 1.68 mm in chickpea and pigeon pea reared larvae, respectively (Table 4.9). Highest eclosion percentage (96.22) was registered in pigeon pea reared larvae followed by pea (94.30), okra (92.56) and tomato (86.29). Lowest eclosion percentage was recorded in case of chick pea reared larvae (Table 4.10). Pupal survivorship was highest in case of okra with 89.22 per cent and least in pea with 75.48 per cent (Table 4.11).

**Table 4. 9 Morphometric measurement (mm) of *B. hebetor* reared on *Helicoverpa armigera* Hub. feeding on different hosts.**

| Stage parameter | Chick Pea | | Pea | | Pigeon pea | | Okra | | Tomato | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean | Range | Mean | Range | Mean |
| Egg length | 0.55-0.67 | 0.60 | 0.47-0.61 | 0.53 | 0.49-0.55 | 0.51 | 0.50-0.60 | 0.55 | 0.50-0.65 | 0.58 |
| Egg breadth | 0.17-0.18 | 0.18 | 0.12-0.13 | 0.12 | 0.10-0.13 | 0.12 | 0.12-0.14 | 0.13 | 0.13-0.17 | 0.15 |
| 1 st day larval length | 0.21-0.25 | 0.23 | 0.31-0.35 | 0.33 | 0.35-0.50 | 0.42 | 0.35-0.38 | 0.37 | 0.28-0.32 | 0.30 |
| 1 st day larval breadth | 0.10-0.13 | 0.12 | 0.12-0.15 | 0.14 | 0.10-0.14 | 0.12 | 0.12-0.15 | 0.14 | 0.12-0.19 | 0.15 |
| 2 nd day larval length | 0.50-0.65 | 0.56 | 0.92-0.99 | 0.95 | 1.25-1.62 | 1.46 | 0.79-0.90 | 0.84 | 0.73-0.77 | 0.75 |
| 2 nd day larval breadth | 0.14-0.18 | 0.16 | 0.15-0.20 | 0.18 | 0.22-0.28 | 0.25 | 0.22-0.25 | 0.23 | 0.18-0.20 | 0.19 |
| 3rd day larval length | 1.90-2.01 | 1.96 | 2.50-2.65 | 2.57 | 2.80-3.01 | 2.91 | 2.33-2.40 | 2.34 | 2.25-2.34 | 2.30 |
| 3rd day larval breadth | 0.88-0.93 | 0.90 | 0.93-1.00 | 0.97 | 1.00-1.04 | 1.02 | 1.00-1.05 | 1.02 | 0.80-1.00 | 0.90 |
| 4th day larval length | 2.78-2.95 | 2.86 | 2.99-3.05 | 3.01 | 3.68-3.79 | 3.74 | 3.0-3.08 | 3.03 | 2.86-2.99 | 2.92 |
| 4th day larval breadth | 1.00-1.05 | 1.03 | 1.00-1.10 | 1.06 | 1.32-1.35 | 1.33 | 1.25-1.34 | 1.29 | 1.19-1.25 | 1.22 |
| Pupal cocoon length | 3.50-3.64 | 3.55 | 3.55-4.00 | 3.77 | 4.00-4.14 | 4.05 | 3.45-3.75 | 3.62 | 3.49-3.65 | 3.57 |
| Pupal cocoon breadth | 1.10-2.02 | 1.51 | 1.25-2.00 | 1.60 | 1.50-2.00 | 1.68 | 1.48-1.59 | 1.55 | 1.20-1.62 | 1.45 |
| male adult length | 2.50-3.50 | 2.90 | 2.90-3.50 | 3.13 | 2.98-3.25 | 3.08 | 2.75-2.85 | 2.78 | 2.75-3.00 | 2.88 |
| male adult breadth (wing expansion) | 3.00-3.50 | 3.17 | 3.90-4.25 | 4.03 | 3.95-4.75 | 4.40 | 3.25-3.35 | 3.28 | 3.00-3.65 | 3.22 |
| female adult length | 2.90-3.50 | 3.20 | 3.50-3.75 | 3.58 | 3.20-3.75 | 3.46 | 3.25-3.65 | 3.48 | 2.95-3.05 | 3.00 |
| female adult breadth (wing expansion) | 3.85-4.0 | 3.92 | 4.00-4.50 | 4.25 | 4.35-4.65 | 4.50 | 4.0-4.55 | 4.27 | 3.50-3.55 | 3.52 |
| Ovipositor length of female | 0.30-0.33 | 0.32 | 0.35-0.45 | 0.39 | 0.41-0.45 | 0.43 | 0.31-0.38 | 0.35 | 0.31-0.35 | 0.34 |

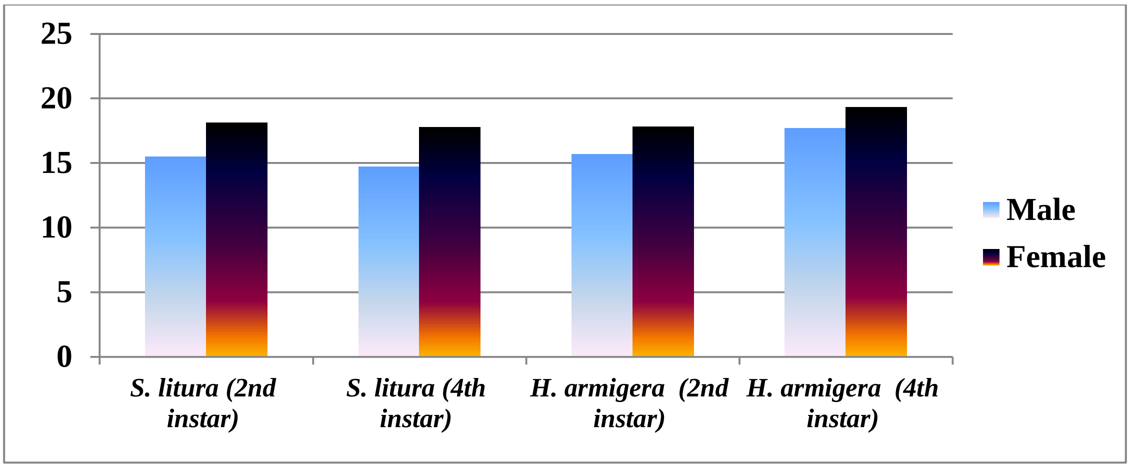



**Fig. 4.10 Total developmental period of male and female (Days) *B. hebetor* reared on *S. litura* and *H. armigera* Hub**

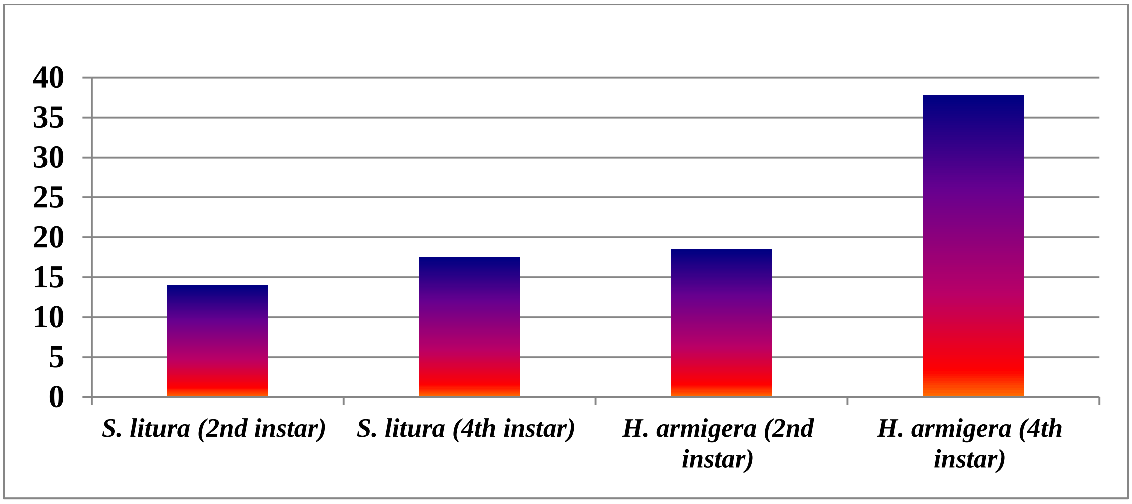



**Fig. 4.11 Fecundity of *B. hebetor* on *S. litura* and *H. armigera***

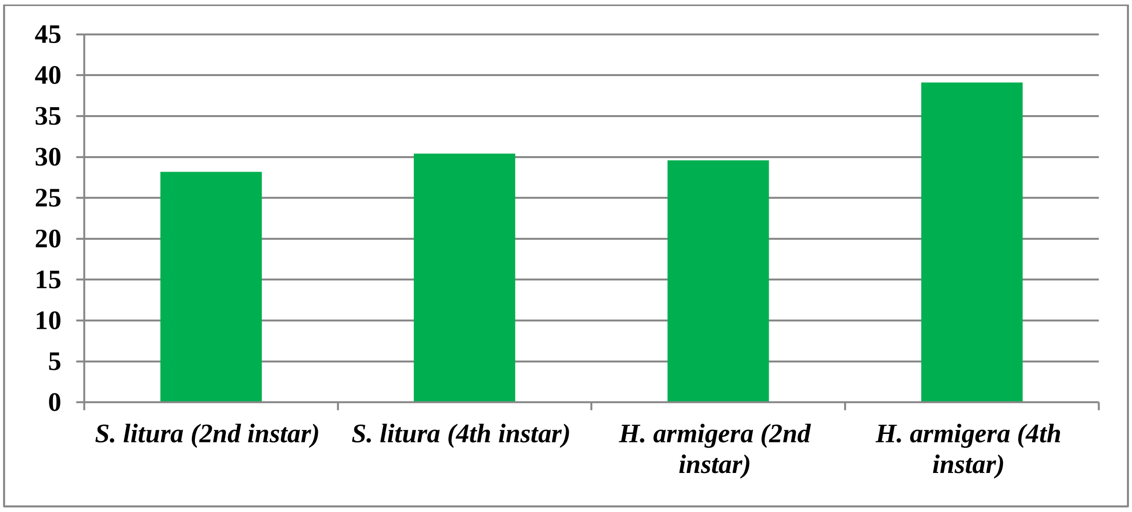
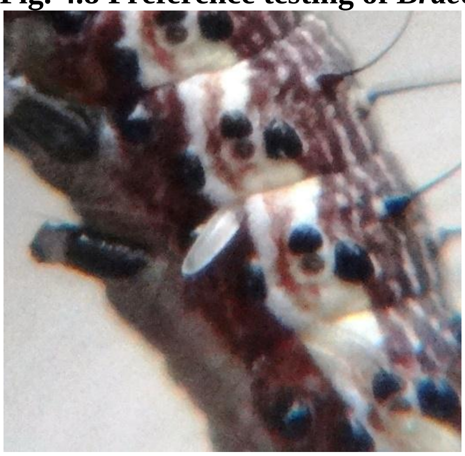



**Fig. 4.12 Per cent survivability from egg-adult of *B. hebetor* on *S. litura* and *H. armigera***

**Fig. 4.8 Preference testing of *Bracon* spp. on *H. armigera* fed on different hosts.**



**Egg**

**Larvae**

**Cocoons**

**Adults**

**Fig. 4.9 Biology of *Bracon hebetor* on *Helicoverpa armigera***

### 4.2.4 Adult

The colour variation of adults of *B. hebetor* was common with variable pterostigma having dark brown, sometimes with a large pale basal spot; body completely yellowish brown to dark brown or black. The last abdominal segment of the adult female was acute and possessed very short ovipositor and the last abdominal segment of male being almost round (Fig. 4.9). The body length (head to end of abdomen) of female was larger than that of male. Maximum length of adult male was found in pea reared larvae 3.13 and minimum length was observed on okra reared larvae with 2.78 mm. The minimum and maximum wing span of adult male were 3.17 and 4.40 mm recorded in chick pea and pigeon pea reared larvae, respectively. Maximum and minimum female body length was recorded 3.00 and 3.58 mm in tomato and pea reared larvae, respectively. Minimum and maximum wing span of adult female was 3.25 and 4.50 mm in tomato and pigeon pea reared larvae, respectively. The longest ovipositor of female was measured 0.43 mm in pigeon pea reared larvae, however, shortest ovipositor (0.32 mm) was recorded in chick pea reared larvae (Table 4.9). Highest viability percentage (84.0 %) was registered in case of pigeon pea followed by tomato (77.43 %), okra (72.98 %) and chickpea (60.63 %). However, lowest viability percentage (51.03 %) was noticed in pea reared larvae (Table 4.10). Egg-adult survivorship was highest (48.33 %) in pigeon pea and least in chick pea (39.0 %) reared larvae (Table 4.11).

The shortest life cycle (egg to adult) of *Bracon hebetor* was recorded in pea reared larvae with 14.81 days and longest developmental period on chick pea reared larvae of 15.80 days. The minimum adult longevity of female (5.60 days) was found in chickpea reared larvae, maximum adult longevity of female (7.90 days) was found in pigeon pea reared larvae, minimum and maximum developmental days of female was recorded 17.06 and 18.10 days in pea and pigeon pea reared larvae, respectively (Fig. 4.4). The minimum adult longevity of male (4.10 days) was found in chickpea reared larvae with the maximum developmental period of 15.80 days, whereas the maximum adult longevity (5.40 days) was found in okra reared larvae. Minimum developmental days of 14.80 days was recorded in pea reared larvae (Table 4.8).

**Table 4.10. Influence of six hosts on egg hatching, fecundity and sex ratio of *B. hebetor*.**

| S/N | Host species | Fecundity* | Egg hatching (%)** | Eclosion (%)** | Viability (%)** | Sex ratio (F : M) |
|---|---|---|---|---|---|---|
| **1** | Chick pea | 45.80<br>(6.77)b | 79.33<br>(63.17) | 76.08<br>(62.12)b | 60.63<br>(51.15)bc | 1 : 1.68 |
| **2** | Pea | 58.60<br>(7.71)a | 89.08<br>(70.82) | 94.30<br>(75.40)a | 51.03<br>(45.58)c | 1 : 1.72 |
| **3** | Pigeon pea | 71.60<br>(8.49)a | 91.00<br>(75.93) | 96.22<br>(79.09)a | 84.00<br>(66.97)a | 1 : 1.40 |
| **4** | Okra | 59.60<br>(7.77)a | 86.52<br>(68.78) | 92.56<br>(74.95)a | 72.98<br>(58.99)ab | 1 : 1.53 |
| **5** | Tomato | 60.80<br>(7.84)a | 84.70<br>(68.37) | 86.29<br>(68.78)ab | 77.43<br>(62.20)a | 1 : 1.49 |
| | **SEm ±** | **0.30** | **2.74** | **3.09** | **2.78** | **-** |
| | **CD at 5%** | **0.91** | **NS** | **9.20** | **8.25** | **-** |
| | **C. V. (%)** | **8.92** | **8.85** | **9.61** | **10.90** | **-** |

* Figures in parenthesis are $\sqrt{x+0.5}$ transformed values.

** Figures in parenthesis are Arc sin transformed values.

Same letter in a column are not significantly different.

**Table 4.11: Percentage of survival of immature stages of *Bracon hebetor* on *H. armigera* reared on different host species.**

| S. N. | Host | Survivorship (%) | | | |
|---|---|---|---|---|---|
| | | **Egg** | **Larva** | **Pupa** | **Egg-adult** |
| **1** | Chick pea | 68.45 (56.06) | 75.53 (60.70) | 76.07 (61.03)bc | 39.00 (38.59) |
| **2** | Pea | 71.98 (58.29) | 76.44 (60.98) | 75.48 (60.41)c | 41.61 (40.13) |
| **3** | Pigeon pea | 69.92 (57.05) | 78.33 (62.57) | 87.34 (69.63)a | 48.33 (43.94) |
| **4** | Okra | 71.50 (58.18) | 71.13 (58.0) | 89.22 (71.29)a | 45.31 (42.25) |
| **5** | Tomato | 74.31 (59.64) | 73.72 (59.23) | 84.26 (66.71)ab | 46.05 (42.72) |
| | **SEm ±** | **0.88** | **1.10** | **2.55** | **1.49** |
| | **CD at 5%** | **NS** | **NS** | **6.28** | **NS** |
| | **C. V. (%)** | **11.67** | **9.38** | **7.24** | **12.80** |

Figures in parenthesis are Arc sin transformed values.

In this study the longevity of female was longer than male as female had the capacity to recover resources by reabsorbing eggs and were also larger and heavier than males due to slower rate of weight loss than that of males (Griggs, 1959).

Saadat *et al*. (2014) in their studies indicated that the *B. hebetor* is a gregarious larval ectoparasitoid, when reared in the laboratory at 25±1 $^{o}$C and 65±5% RH, on the *Helicoverpa armigera* required an average of 15.73 days for completion of its development from the egg to adults. The eggs hatched within 2.71 days, after oviposition and the larval and pupal stages were completed within 5.68 and 7.36 days, respectively which matched with the developmental period but differed in hatching period and larval duration which was shorter in the present findings.

The present findings matched with Alam *et al*. (2014) in almost all respects in which they recorded the duration of different developmental stages and other related parameters of *B. hebetor* reared on the larvae of *G. mellonella*. at 25±2°C, 75±5% RH and 12 hr photoperiod. The mean incubation period was of 1.48 days and larval period of 3.17 days, the pupal period lasted for 4.35 days with a range from 4.0 - 6.0 days and the mean developmental period of the parasitoid on *G. mellonella* was 9.60 days. The females lived longer (20.0 days) than males (14.40 days). They also reported that length of ovipositor in female was 0.48 mm, which varied slightly more with the present finding of 0.43mm.

Thus most of earlier reports were in agreement with the findings of the present study. The biological study is important for mass rearing program in inundative release to ensure successful biological control of insect pests. So, there is a great scope for *Bracon hebetor* to be used as a component of Integrated Pest Management programme for the suppression of lepidopteran pests in Chhattisgarh plains crop ecosystems.

**Table 4.12. Development time (days) of different life-stages of *B. hebetor* reared on *Spodoptera litura* Fab. and *Helicoverpa armigera*.**

| S/N | Host species | Egg | Larva | Pre-pupa | Pupa | Adult | | Female | | | Total life cycle | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Male | Female | Pre-oviposition | Oviposition | Post -oviposition | Male | Female |
| **1** | *Spodoptera litura* (2nd instar) | 1.50 | 4.13ab | 0.78 | 5.03b | 4.06a | 6.69b | 0.51 | 4.59 | 1.59a | 15.50b | 18.13 |
| **2** | *Spodoptera litura* (4th instar) | 1.31 | 3.75b | 0.84 | 4.06c | 4.75ab | 7.81a | 0.67 | 5.31 | 1.83a | 14.72b | 17.78 |
| **3** | *Helicoverpa armigera* (2nd instar) | 1.75 | 4.25ab | 0.94 | 4.38c | 4.38bc | 6.50b | 0.57 | 5.50 | 1.43ab | 15.69b | 17.81 |
| **4** | *Helicoverpa armigera* (4th instar) | 1.50 | 4.69a | 1.00 | 5.63a | 4.88a | 6.50b | 0.67 | 5.00 | 0.83b | 17.69a | 19.31 |
| | **SEm ±** | **0.15** | **0.18** | **0.11** | **0.17** | **0.14** | **0.20** | **0.05** | **0.25** | **0.22** | **0.41** | **0.44** |
| | **CD at 5%** | **NS** | **0.57** | **NS** | **0.52** | **0.45** | **0.64** | **NS** | **NS** | **0.69** | **1.29** | **NS** |
| | **C. V. (%)** | **29.15** | **13.37** | **38.34** | **10.76** | **9.78** | **9.09** | **27.29** | **15.02** | **48.36** | **7.92** | **7.77** |

NS = Not significant.

Same letter in a column are not significantly different.

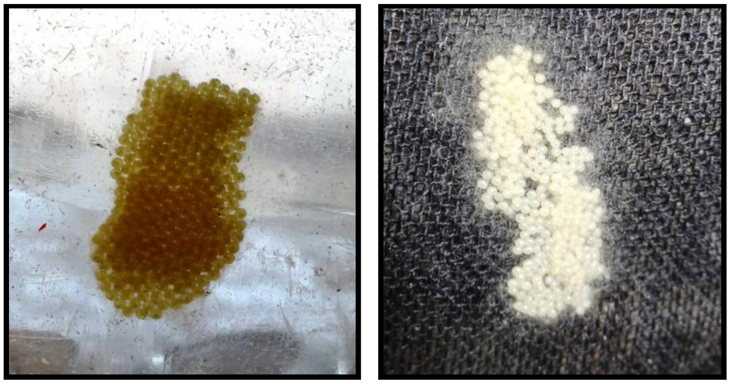


Fig. Eggs of *S. litura*

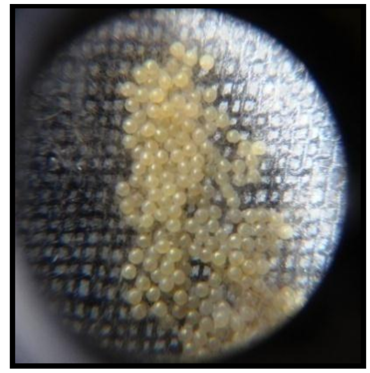


Fig. Microscopic view of eggs

Fig. 1st instar larvae of *S. litura*

Fig. 2nd instar larvae of *S. litura*

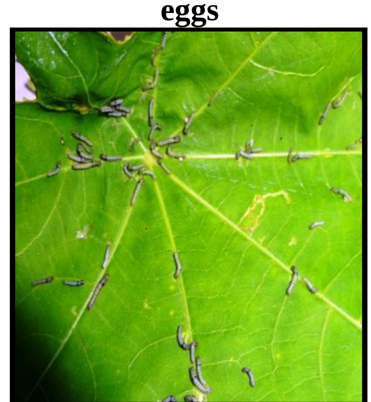


Fig. 3rd instar larvae of *S. litura*

Fig. Fully grown larvae of *S. litura*

**Fig. 4.13 Mass culturing of *Spodoptera litura* Fab. on castor leaves.**

## 4.3 To study the ovipositional preference of *Bracon* spp. on second and fourth instars of host insects.

### 4.3.1 Eggs

All tested instars of host larvae selected were acceptable to the *Bracon hebetor* females for parasitism and oviposition. Highest fecundity of 37.75 eggs was recorded on *H. armigera* ($4^{th}$ instar) followed by 18.50, 17.50 and 14.0 eggs on *H. armigera* ($2^{nd}$ instar), *S. litura* ($4^{th}$ instar) and *S. litura* ($2^{nd}$ instar), respectively. Incubation period in all the treatments were statistically non significant. The lowest life expectancy for the egg period (1.13 days) of *B. hebetor* was registered with *S. litura* ($4^{th}$ instar) followed by *S. litura* ($2^{nd}$ instar) and *H. armigera* ($4^{th}$ instar) with 1.50 days for both insects (Table 4.12). The two species of host larvae with second and fourth instar were evaluated for their ovipositional preference of *Bracon* spp. Highest per cent hatchability of *B. hebetor* eggs were (79.31 %) (Table 4.14) reared on the larvae of *H. armigera* ($4^{th}$ instar) followed by *S. litura* $4^{th}$ and $2^{nd}$ instar larvae with 70.56 and 69.36 per cent, respectively. Lowest hatching percentage (58.21%) was registered in case of *H. armigera* ($2^{nd}$ instar).

### 4.3.2 Larvae

Significantly more time (4.69 days) was required to complete larval duration in case of *H. armigera* ($4^{th}$ instar) in comparison to rest of the host larvae used. Lowest larval duration (3.75 days) was registered in case of *S. litura* ($4^{th}$ instar).

### 4.3.3 Pre-pupa

Pre-pupal period of *B. hebetor* was found to be non significantly differentiated between all the larval host. Highest pre-pupal period (1.0 day) was recorded in case of *H. armigera* ($4^{th}$ instar) as compared to *H. armigera* ($2^{nd}$ instar) with 0.94 days.

### 4.3.4 Pupa

Pupal period was lowest (4.06 days) in case of *S. litura* ($4^{th}$ instar) followed by *H. armigera* ($2^{nd}$ instar) and *S. litura* ($2^{nd}$ instar) with 4.38 and 5.03 days, respectively. Shorter pupal period was exhibited in these three larval hosts over rest of the host larvae used, except *H. armigera* ($4^{th}$ instar) which recorded longest pupal period of 5.63 days.

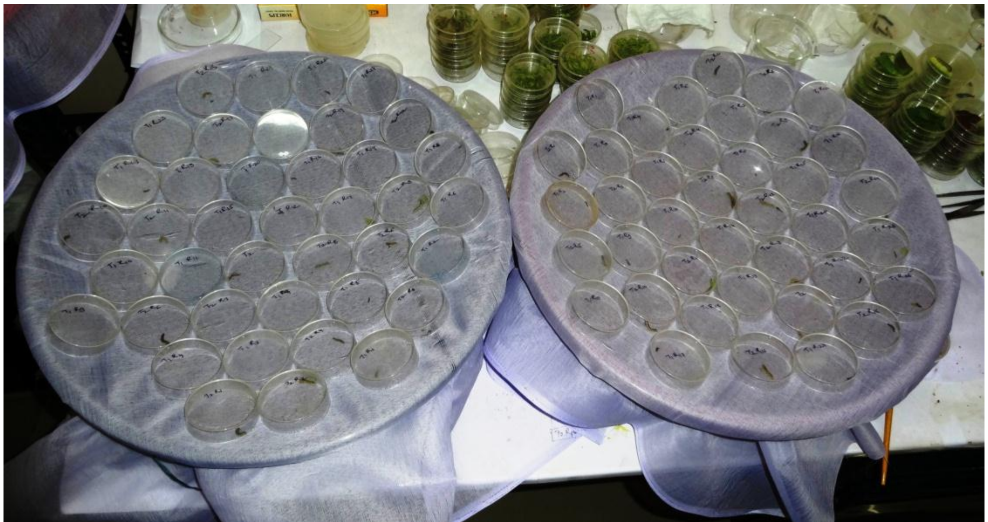
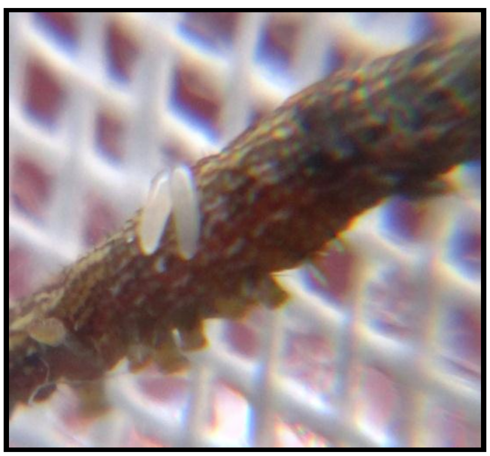
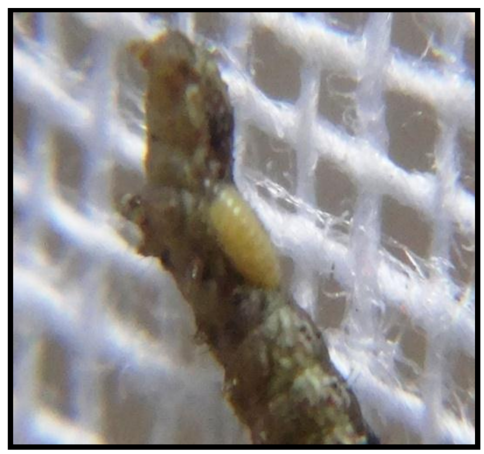


**Fig. 4.14 Testing of oviposition preference of *Bracon* spp. on 2nd and 4th instar larvae of *H. armigera* and *S. litura.***

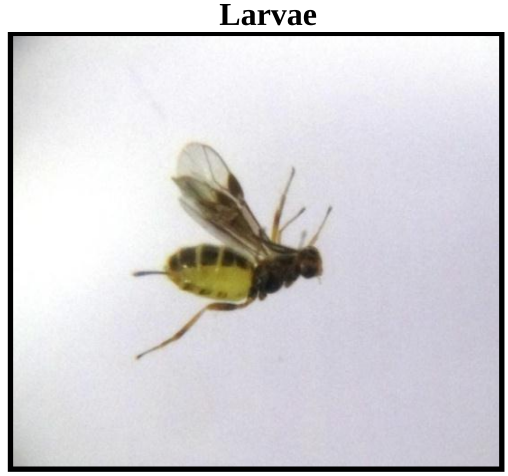


**Egg**



**Larvae**

**Cocoons**



**Adults**

**Fig. 4.15 Life cycle of *B. hebetor* on *S. litura***

**Table 4. 13 Morphometric measurement (mm) of *B. hebetor* reared on *Spodoptera litura* Fab. and *Helicoverpa armigera.***

| Stage parameter of *Bracon hebetor* | *S. litura* (2nd instar) | | *S. litura* (4th instar) | | *H. armigera* (2nd instar) | | *H. armigera* (4th instar) | |
|---|---|---|---|---|---|---|---|---|
| | **Range** | **Mean** | **Range** | **Mean** | **Range** | **Mean** | **Range** | **Mean** |
| **Egg length** | 0.40-0.60 | 0.47 | 0.42-0.46 | 0.44 | 0.49-0.52 | 0.50 | 0.54-0.60 | 0.56 |
| **Egg breadth** | 0.12-0.14 | 0.13 | 0.14-0.16 | 0.15 | 0.12-0.15 | 0.14 | 0.17-0.18 | 0.18 |
| **1 st day larval length** | 0.35-0.40 | 0.38 | 0.40-0.45 | 0.43 | 0.39-0.43 | 0.41 | 0.35-0.45 | 0.40 |
| **1 st day larval breadth** | 0.11-0.15 | 0.13 | 0.14-0.16 | 0.15 | 0.10-0.14 | 0.12 | 0.12-0.15 | 0.14 |
| **2 nd day larval length** | 1.20-1.35 | 1.27 | 1.00-1.75 | 1.42 | 1.50-1.75 | 1.63 | 1.65-1.85 | 1.75 |
| **2 nd day larval breadth** | 0.40-0.45 | 0.42 | 0.20-0.25 | 0.23 | 0.31-0.36 | 0.34 | 0.22-0.25 | 0.23 |
| **3rd day larval length** | 2.20-2.32 | 2.25 | 2.00-2.25 | 2.08 | 2.00-2.33 | 2.16 | 2.18-2.75 | 2.46 |
| **3rd day larval breadth** | 0.85-1.04 | 0.97 | 1.00-1.02 | 1.01 | 1.00-1.01 | 1.00 | 1.00-1.05 | 1.02 |
| **4th day larval length** | 3.00-3.50 | 3.17 | 3.24-3.29 | 3.26 | 3.45-3.57 | 3.49 | 3.70-3.80 | 3.75 |
| **4th day larval breadth** | 1.00-1.25 | 1.15 | 1.29-1.38 | 1.32 | 1.20-1.29 | 1.24 | 1.40-1.43 | 1.14 |
| **Pupal cocoon length** | 3.20-3.33 | 3.26 | 3.55-4.00 | 3.77 | 3.70-3.82 | 3.75 | 3.95-4.04 | 4.00 |
| **Pupal cocoon breadth** | 1.40-1.55 | 1.47 | 1.50-1.65 | 1.56 | 1.47-1.48 | 1.47 | 1.56-1.65 | 1.62 |
| **male adult length** | 2.75-2.90 | 2.82 | 3.00-0.05 | 3.02 | 2.89-2.96 | 2.92 | 3.00-3.25 | 3.12 |
| **male adult breadth (wing expansion)** | 3.00-3.03 | 3.01 | 3.95-4.00 | 3.97 | 3.50-3.65 | 3.55 | 3.50-3.77 | 3.64 |
| **female adult length** | 3.10-3.15 | 3.12 | 3.29-3.65 | 3.46 | 3.50-3.58 | 3.53 | 3.50-3.67 | 3.60 |
| **female adult breadth (wing expansion)** | 3.00-3.50 | 3.25 | 4.12-4.18 | 4.15 | 4.20-30 | 4.25 | 4.20-4.50 | 4.32 |
| **Ovipositor length of female** | 0.30-0.33 | 0.32 | 0.40-0.45 | 0.42 | 0.34-0.35 | 0.35 | 0.44-0.47 | 0.45 |

### 4.3.5 Male

Among the hosts larvae, significantly less duration of male longevity (4.06) was registered in case of *S. litura* (2nd instar). Highest adult male longevity was recorded in *H. armigera* (4th instar) with 4.88 days followed by *S. litura* (4th instar) with 4.73 days.

### 4.3.6 Female

Female longevity was found to be highest in case of *S. litura* (4th instar) with 7.81 days. *S. litura* (2nd instar) stood second in rank by exhibiting 6.69 days. Both these larval hosts differed from rest of larvae by registering significantly higher longevity over remaining host larvae. With respect to least female longevity *Bracon* performed equally on *H. armigera* in both instar with 6.5 days.

### 4.3.7 Pre-oviposition

Pre-oviposition period was found to be of 0.51 to 0.67 days on different host larvae tested with non significant differences between them. Relatively low pre-oviposition period was found in case of *S. litura* (2nd instar) and *H. armigera* (2nd instar) with 0.51 days and 0.57, respectively.

### 4.3.8 Oviposition

Significantly highest and lowest oviposition period was recorded in *H. armigera* (2nd instar) and *S. litura* (4th instar) of 5.50 and 5.31 days, respectively. With respect to oviposition period, significant differences were registered on all the host larvae. Significantly highest fecundity was registered in case of *H. armigera* (4th instar) with an average 37.75 eggs/female followed by *H. armigera* (2nd instar) with 18.50 eggs per female. On the other hand, significantly least number of eggs per female were recorded in *S. litura* (2nd instar) of 17.50 eggs/ female.

### 4.3.9 Post –oviposition

In terms of post –ovipositional period (days) of *S. litura* (2nd instar), *S. litura* (4th instar) and *H. armigera* (2nd instar) were at par with each other. Significantly, highest post-ovipositional period was recorded in *H. armigera* (2nd instar) with 1.83 days as compared to *S. litura* (4th instar) which stood second in position by registering 1.59 days. Significantly lowest post-ovipositional period was exhibited (0.83 days) by

**Table 4.14. Influence of six hosts on fecundity, egg hatching, eclosion, viability and sex ratio of *B. hebetor.***

| S/N | Host species | Fecundity* | Egg hatching (%)** | Eclosion (%)** | Viability (%)** | Sex ratio (F : M) |
|---|---|---|---|---|---|---|
| **1** | *Spodoptera litura* (2nd instar) | 14.0 (3.69)b | 69.36 (56.83)ab | 55.98 (48.51) | 25.25 (29.94)a | 1 : 1.41 |
| **2** | *Spodoptera litura* (4th instar) | 17.50 (4.14)b | 70.56 (57.45)ab | 63.72 (53.09) | 39.11 (38.67)a | 1 : 1.57 |
| **3** | *Helicoverpa armigera* (2nd instar) | 18.50 (4.21)b | 58.21 (49.89)b | 60.84 (51.49) | 30.43 (33.27)b | 1 : 1.60 |
| **4** | *Helicoverpa armigera* (4th instar) | 37.75 (6.12)a | 79.31 (63.23)a | 68.98 (56.29) | 44.63 (41.85)a | 1 : 1.49 |
| | **SEm ±** | **1.09** | **2.14** | **1.14** | **1.33** | **-** |
| | **CD at 5%** | **0.70** | **7.59** | **NS** | **5.04** | **-** |
| | **C. V. (%)** | **15.21** | **13.04** | **12.12** | **13.71** | **-** |

* Figures in parenthesis are $\sqrt{x+0.5}$ transformed values.

** Figures in parenthesis are Arc sin transformed values.

Same letter in a column are not significantly different.

**Table 4.15 Percentage of survival of immature stages of *Bracon hebetor* reared on *Spodoptera litura* and *Helicoverpa armigera*.**

| S. N. | Host | Survivorship (%) | | | |
|---|---|---|---|---|---|
| | | **Egg** | **Larva** | **Pupa** | **Egg-adult** |
| **1** | *Spodoptera litura* (2nd instar) | 17.50 (24.54)b | 12.13 (20.17)b | 9.25 (17.37)b | 28.19 |
| **2** | *Spodoptera litura* (4th instar) | 16.00 (23.24)b | 11.25 (19.26)b | 7.38 (15.53)b | 30.43 |
| **3** | *Helicoverpa armigera* (2nd instar) | 18.50 (25.06)b | 10.25 (18.37)b | 7.50 (15.60)b | 29.60 |
| **4** | *Helicoverpa armigera* (4th instar) | 37.75 (37.84)a | 30.00 (33.10)a | 21.88 (27.58)a | 39.10 |
| | **SEm ±** | **1.0** | **0.84** | **0.92** | **1.61** |
| | **CD at 5%** | **4.78** | **3.96** | **4.08** | **NS** |
| | **C. V. (%)** | **16.89** | **17.05** | **20.98** | **16.50** |

Figures in parenthesis are Arc sin transformed values.

*B. hebetor* larvae reared on *H. armigera* (4$^{th}$ instar) which proves that host influenced significantly on egg-laying potential of larval parasitoid (Table 2).

**4.3.10 Total life-cycle**

Highest duration of adult longevity of *B. hebetor* female was recorded in *S. litura* (4$^{th}$ instar) with 7.81 days followed by *S. litura* (2$^{nd}$ instar) with 6.69 days. Both these host larvae differed from remaining hosts by exhibiting significantly higher duration. Least duration of life-cycle of female was found in *S. litura* (4$^{th}$ instar) with 17.78 days which was found to be non significant with other stages of host larvae tested. Longest life-cycle was registered in *H. armigera* (4$^{th}$ instar) with 19.31 days. Different trend of life-cycle on different host larvae was noticed in male insects where significantly highest duration was registered in case of *H. armigera* (4$^{th}$ instar) with 17.69 days followed by *H. armigera* (2$^{nd}$ instar) with 15.69 days. Among the different hosts, shortest duration of male life-cycle was recorded in *S. litura* (4$^{th}$ instar) with the period of 14.72 days (Table 4.12).

**4.3.11 Sex ratio**

The Sex ratio study on *B. hebetor*, revealed that males dominated on both hosts. The sex ratio of the parasitoid reared on *S. litura* (2$^{nd}$ instar) was 1: 1.41 followed by *H. armigera* (4$^{th}$ instar) with 1: 1.49. On the other hand male population predominated when *B. hebetor* was reared on *H. armigera* (2$^{nd}$ instar) with 1: 1.60 followed by *S. litura* (4$^{th}$ instar) with 1: 1.57 (Table 4.14).

Lowest egg period of *B. hebetor* was registered in *S. litura* (4$^{th}$ instar) followed by *S. litura* (2$^{nd}$ instar) and *H. armigera* (4$^{th}$ instar) with 1.31 and 1.50 days for both insects. Similar findings were reported by Dabhi *et al*. (2013) who reported average egg period (1.43 days), larva (3.84 days), pre-pupa (1.08 days), pupa (5.06 days), adult male (6.73 days), pre-oviposition (0.73 days) of *B. hebetor* reared on *H. armigera*, but differed with the statement that adult female lived for 20.92 days, oviposition period continued for the 19.87 days and post-oviposition period recorded for 3.79 days, male longevity for 10.50 days and female longevity for 27.64 days.

The above findings are in line with those of Dabhi *et al*. (2013) who reported lowest larval period (3.09 days), highest pupal period for 5.92 days, less male longevity for 5.09 days on *S. litura.* Alam *et al*. (2014) also recorded that the incubation period was of 1.38 days, larval period of 3.10 days, pupal period with 4.80 days, egg-adult period with 9.29 days of *B. hebetor* for *H. armigera* however, longest egg- adult period for 11.4 days and lowest survival per cent of *B. hebetor* was recorded on *S. litura.*

From the above results it can be concluded that *H. armigera* (4$^{th}$ instar) was acceptable to the *Bracon hebetor* females for oviposition and found to be a suitable host for laboratory mass rearing of *B. hebetor.*

This finding is supported by few earlier studies of Dabhi *et al*. (2013) and Alam *et al*. (2014) who found *H. armigera* as the most suitable host for the development of *B. hebetor* with respect to number of eggs laid, percentage of egg hatch and percentage of adult emergence better than *S. litura.*

## 4.4 To study the biology of *Bracon hebetor* Say (Hymenoptera : Braconidae) on various lepidopteran larvae under laboratory conditions.

### 4.4.1 Fecundity

All six host species tested for the present study were acceptable to the *Bracon hebetor* females for parasitism and oviposition. The highest fecundity (112.80 eggs/female) was observed on the larvae of the rice meal moth, *Corcyra cephalonica*, which was statistically similar to the larvae of teak skeletonizer, *Eutectona macheralis* with 103.20 eggs/female and significantly higher compared to other host larvae. Significantly lowest fecundity (22.80eggs/female) was observed on the larvae of *Plutella xylostella*. The findings of the present study revealed that the entire host species tested might be recorded as acceptable hosts. When a parasitoid accepts a host for paralyzing and ovipositing it may be considered as an acceptable host. The second lowest egg number was found on *Papilio demoleus* larvae (37 eggs/female) followed by *Leucinodes orbonalis* (87.40 eggs/female) and *Earias vittella* larvae (59 eggs/female) (Table 4.17 and Fig. 4.17).

**Table 4.16. Developmental time (days) of different life-stages of *B. hebetor* reared on six different hosts.**

| S/N | Host species | Egg | Larva | Pre-pupa | Pupa | Adult | | Female | | | Total life cycle | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Male | Female | Pre-oviposition | Oviposition | Post -oviposition | Male | Female |
| 1 | *Corcyra cephalonica* Stainton | 1.50 | 3.60bcd | 0.78 | 4.60 | 6.40ab | 10.20ab | 0.62b | 8.20a | 2.00c | 16.88 | 20.68ab |
| 2 | *Leucinodes orbonalis* Guenee | 1.70 | 4.10ab | 0.55 | 4.70 | 7.50a | 10.70a | 0.58b | 7.72a | 2.40c | 18.55 | 21.75a |
| 3 | *Earias vittella* Fab. | 1.50 | 3.30cd | 0.65 | 4.60 | 6.90a | 9.70bc | 0.61b | 6.90b | 2.19bc | 16.95 | 19.75bc |
| 4 | *Papilio demoleus* Lin. | 1.73 | 4.35a | 0.71 | 5.42 | 5.65b | 8.80de | 1.05a | 4.60c | 3.05ab | 17.86 | 21.01ab |
| 5 | *Plutella xylostella* Linn. | 1.20 | 3.05d | 0.55 | 4.30 | 7.10a | 9.20cd | 1.15a | 4.60c | 3.45a | 16.20 | 18.30c |
| 6 | *Eutectona macheralis* | 1.75 | 3.80abc | 0.80 | 4.60 | 5.50b | 8.05e | 1.05a | 4.80c | 2.20bc | 16.45 | 19.00c |
| | **SEm ±** | **0.12** | **0.19** | **0.06** | **0.23** | **0.33** | **0.26** | **0.07** | **0.31** | **0.32** | **0.52** | **0.41** |
| | **CD at 5%** | **NS** | **0.62** | **NS** | **NS** | **1.16** | **0.87** | **0.26** | **0.90** | **0.99** | **NS** | **1.45** |
| | **C. V. (%)** | **20.36** | **12.93** | **25.14** | **12.44** | **13.68** | **7.10** | **24.25** | **11.13** | **30.80** | **8.75** | **5.53** |

NS = Not significant.

Same letter in a column are not significantly different.

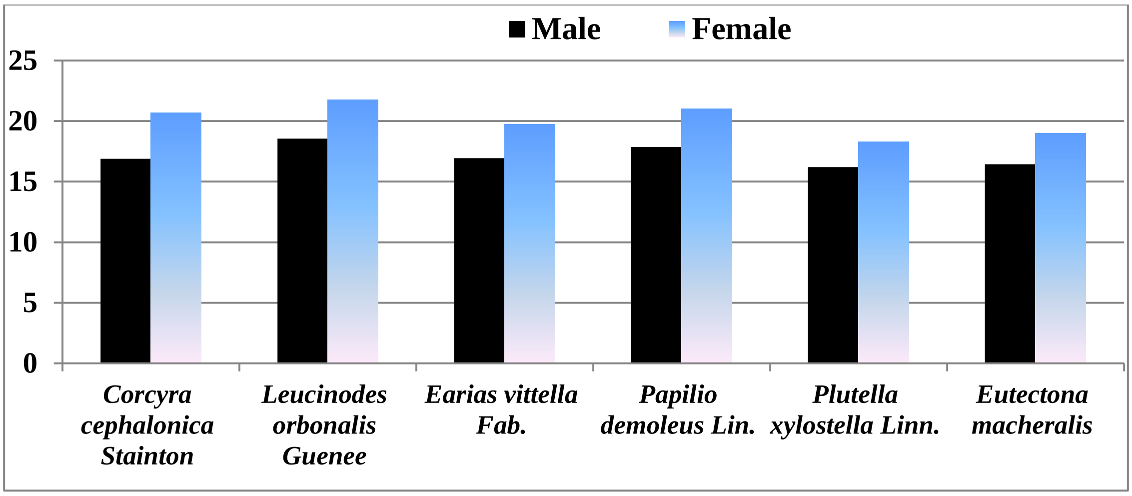



**Fig. 4.16 Total developmental period (Days) of male and female *B. hebetor* reared on different lepidopteran hosts.**

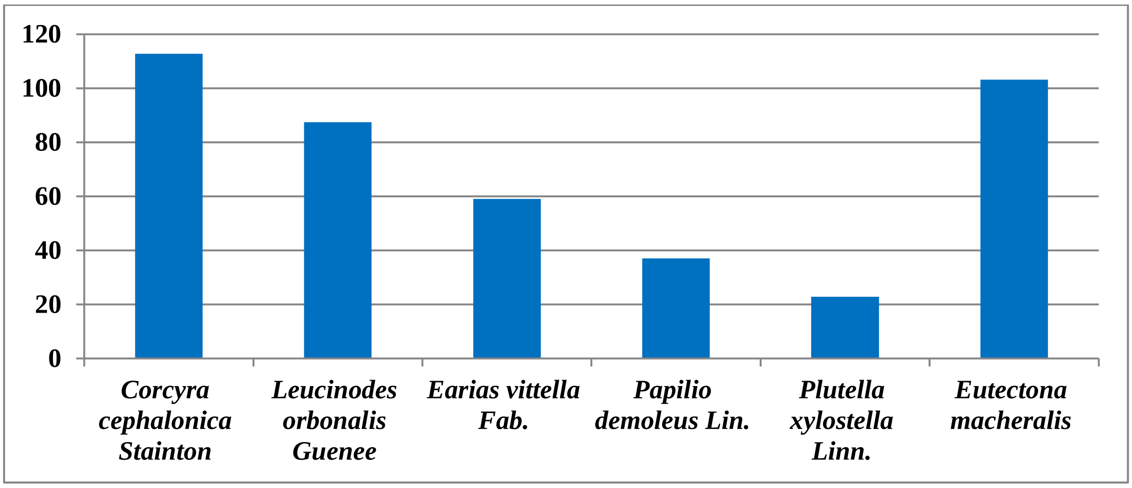



**Fig. 4.17 Fecundity of *B. hebetor* on different lepidopteran larvae.**

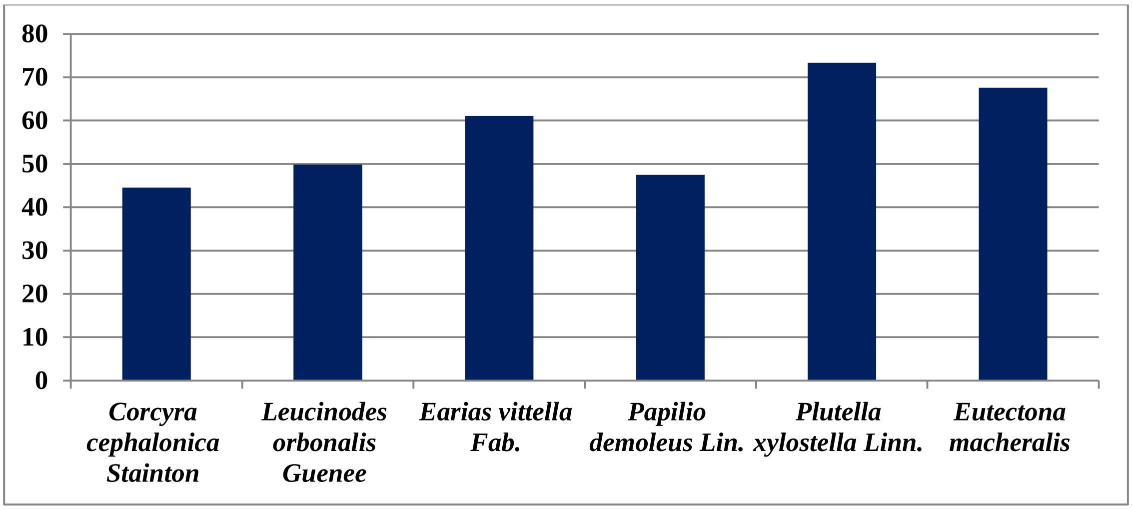



**Fig. 4.18 Per cent survivability from egg-adult of *B. hebetor* on different lepidopteran larvae.**

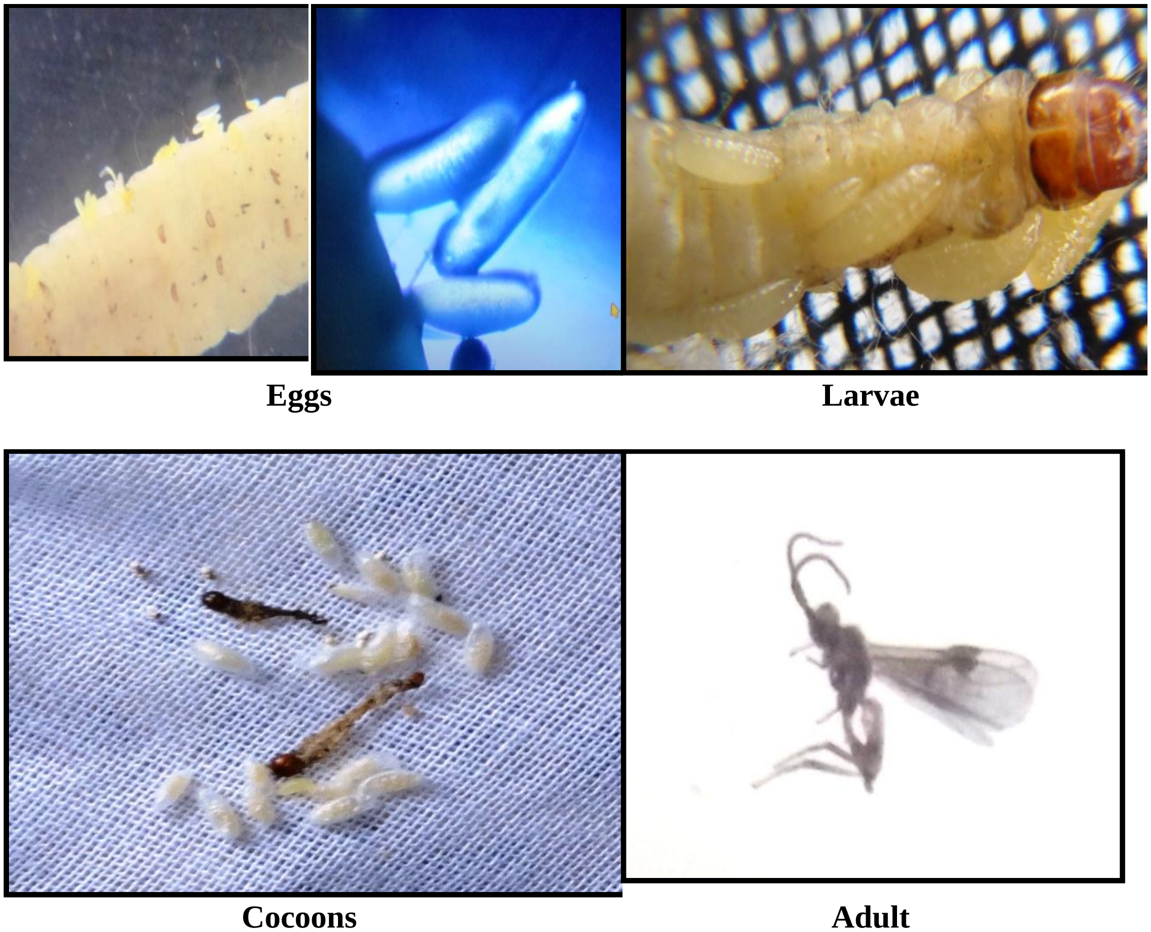



**Fig. 4.19 Life cycle of *B. hebetor* on *Corcyra cephalonica* larvae**

**Table 4.17. Influence of six hosts on fecundity, egg hatching and sex ratio of *B. hebetor*.**

| S/N | Host species | Fecundity* | Egg hatching (%)** | Eclosion (%)** | Viability (%)** | Sex ratio (F : M) |
|---|---|---|---|---|---|---|
| **1** | *Corcyra cephalonica* Stainton | 112.80 (10.65)a | 70.79 (57.73)c | 91.25 (73.44)a | 44.53 (41.76)d | 1 : 1.67 |
| **2** | *Leucinodes orbonalis* Guenee | 87.40 (9.38)b | 60.74 (68.38)ab | 84.74 (68.85)a | 51.13 (45.63)cd | 1 : 1.22 |
| **3** | *Earias vittella* Fab. | 59.00 (7.70)c | 79.00 (62.74)bc | 89.33 (71.75)a | 61.09 (51.42)bc | 1 : 1.87 |
| **4** | *Papilio demoleus* Lin. | 37.00 (6.09)d | 88.11 (69.92)a | 71.30 (57.86)b | 47.78 (43.69)d | 1 : 1.69 |
| **5** | *Plutella xylostella* Linn. | 22.80 (4.87)e | 86.20 (68.38)ab | 93.56 (73.01)a | 73.34 (59.08)a | 1 : 1.13 |
| **6** | *Eutectona macheralis* | 103.20 (10.18)ab | 85.94 (68.68)ab | 91.33 73.03a | 67.54 (55.35)ab | 1 : 1.88 |
| | **SEm ±** | **0.31** | **2.36** | **3.22** | **2.36** | **0.12** |
| | **CD at 5%** | **0.93** | **6.94** | **9.18** | **6.93** | **-** |
| | **C. V. (%)** | **8.69** | **8.01** | **10.03** | **10.67** | **-** |

* Figures in parenthesis are $\sqrt{x+0.5}$ transformed values.

** Figures in parenthesis are Arc sin transformed values.

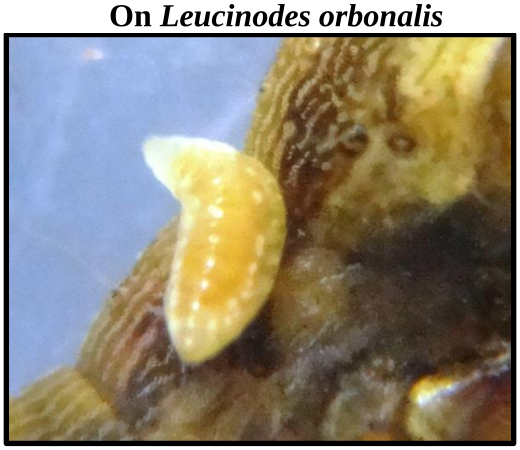
Same letter in a column are not significantly different.

**On chick pea reared *H. armigera* (4th instar)**

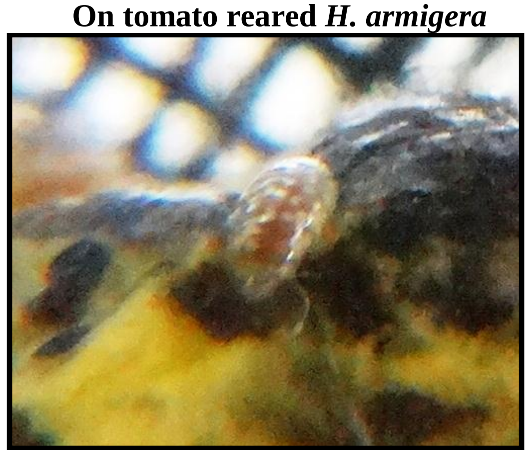
**On chick pea reared *H. armigera* (2nd instar)**

**On *Leucinodes orbonalis***

**On tomato reared *H. armigera***



**On okra reared *H. armigera***



**On *Papilio demoleus***

**Fig. 4.20 Colour pattern of *B. hebetor* larvae on different host.**

The duration of the embryonic development of *H. hebetor* depended on the host on which it develops (Table 4.16). Embryonic developmental period for all tested host insects were statistically non significant.

The least fecundity *ie*., the number of eggs laid by parasitoids was recorded on *P. xylostella* and the highest on *C. cephalonica.* The statistical analysis of the present findings helped to place the duration of the embryonic period of *H. hebetor* into three groups. The first group included those with the highest fecundity namely, *Corcyra cephalonica* and *E. macheralis.* The second group those with an intermediate fecundity included *L. orbonalis* and *E. vittella*. Finally, the third group with the shortest fecundity was observed in *P. xylostella* and *P.demoleus* (Table 17).

### 4.4.2 Hatching percentage or hatchability

The percentage of hatchability recorded for the parasitoids reared on six different hosts differed significantly. Highest hatchability was observed on eggs deposited on larvae of *P. demoleus* (88.11%) and lowest on those of *L. orbonalis* (60.74%). The percentage egg hatch was 70.79, 79.00, 86.20 and 85.94 %, respectively for *C. cephalonica, E. vittella, P. xylostella* and *E. macheralis*. (Table 4.17).

### 4.4.3 Larval period

Larval period of the parasitoid on the six tested hosts differed significantly, with longest larval period recorded for those that developed on *P. demoleus* (4.35 days) and shortest on *P. xylostella* (3.05 days). Larval developmental periods on *C. cephalonica*, *L. orbonalis*, *E. vittella* and *E. macheralis* was 3.60, 4.10, 3.30 and 3.80 days, respectively (Table 4.16).

### 4.4.4 Pupal period

The pupal periods of the parasitoids reared on different lepidopteran hosts were statistically non significant, with the shortest period recorded on *P. xylostella* (4.30 days) and the longest on *P. demoleus* (5.42 days). Pupal developmental period on *C. cephalonica*, *L. orbonalis*, *E. vittella* and *E. macheralis* was 4.60, 4.70, 4.60 and 4.60

**On *Eutectona macheralis***

**On pigeon pea reared *H. armigera***

**On *Earias vittella***

**On tomato reared *H. armigera* (2nd instar)**

**On pea reared *H. armigera***

**On tomato reared *H. armigera* (4th instar)**

**Fig 4.21 Colour pattern of *B. hebetor* larvae on different host.**

days, respectively. Maximum eclosion per cent was noticed on *P. xylostella* (93.56 %) and minimum on *P. demoleus* (71.30 %) (Table 4.16).

### 4.4.5 Total developmental period

Non significant differences were noticed in total developmental periods of adult male from egg to adult of this hymenopterous larval ecto-parasitoid reared on *C. cephalonica*, *L. orbonalis, E. vittella, P. demoleus, P. xylostella* and *E. macheralis* of 16.88, 18.55, 16.95, 17.86, 16.20 and 16.45 days, respectively. The total developmental period of adult female differed significantly on different hosts *C. cephalonica*, *L. orbonalis* and *P. demoleus* which were at par with each other but differed significantly from *E. vittella, P. xylostella* and *E. macheralis* (Table 4.16 and Fig. 4.16).

### 4.4.6 Percent survivability

Data presented in Table 4.16 indicated that maximum survivability was recorded in *P. xylostella* (73.34 %) and minimum in *C. cephalonica* (44.53 %) (Table 4.16 and Fig. 4.18).

### 4.4.7 Sex ratio

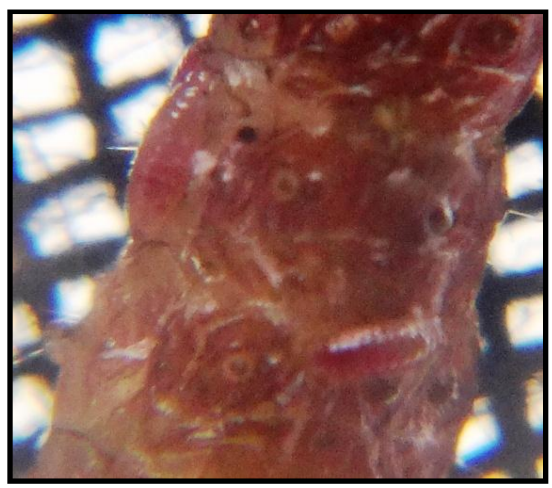
The off-spring sex ratio (female/total) of *H. hebetor* reared on the different hosts differed significantly. The sex ratio was greatest for those reared on *E. macheralis* (1:1.88) and lowest for those reared on *P. xylostella* (1:1.13). The sex ratio was 1:1.67, 1:1.22, 1:1.87 and 1:1.69 for those reared on *C. cephalonica, L. orbonalis. E. vittella* and *P. demoleus,* respectively (Table 4.17).

The current study revealed that although *B. hebetor* could parasitize six different lepidopteran hosts, tested its developmental period, off-spring sex ratio, percentage egg hatchability significantly depended on the hosts *C. cephalonica*, *P. xylostella* and *E. macheralis* proved to be the superior hosts in terms of all the parameters evaluated. However, in terms of developmental period and off-spring sex ratio, *E. macheralis* proved to be better host than *P. xylostella* as the total developmental period of the female parasitoid reared on *P. xylostella* was shorter

**On *Corcyra cephalonica***

**On *Spodoptera litura***

**On *Leucinodes orbonalis* (Initial stage)**



**On *Leucinodes orbonalis* (Later stage)**

**Fig 4.22 Colour pattern of *B. hebetor* larvae on different host.**

**Table 4.18 Percentage of survival of immature stages of *Bracon hebetor* reared on six lepidopteran host species.**

| S. N. | Host | Survivorship (%) | | | |
|---|---|---|---|---|---|
| | | **Egg** | **Larva** | **Pupa** | **Egg-adult** |
| **1** | *Corcyra cephalonica* Stainton | 70.79 (57.75) [bc] | 68.92 (56.70) [c] | 91.25 (73.47) [a] | 44.53 (41.77) [d] |
| **2** | *Leucinodes orbonalis* Guenee | 68.21 (56.29) [c] | 77.07 (61.91) [bc] | 94.37 (76.54) [a] | 49.81 (44.90) [cd] |
| **3** | *Earias vittella* Fab. | 82.47 (65.39) [ab] | 82.24 (65.20) [ab] | 87.99 (70.31) [a] | 61.09 (51.44) [bc] |
| **4** | *Papilio demoleus* Lin. | 88.11 (69.94) [a] | 76.51 (61.41) [bc] | 71.30 (57.89) [b] | 47.78 (43.71) [d] |
| **5** | *Plutella xylostella* Linn. | 86.20 (68.40) [a] | 90.78 (72.45) [a] | 91.11 (73.04) [a] | 73.34 (59.11) [a] |
| **6** | *Eutectona macheralis* | 85.94 (68.71) [a] | 85.96 (68.04) [ab] | 91.33 (73.06) [a] | 67.54 (55.37) [ab] |
| | **SEm ±** | **3.20** | **2.89** | **3.12** | **4.37** |
| | **CD at 5%** | **8.63** | **7.95** | **6.36** | **7.59** |
| | **C. V. (%)** | **10.27** | **9.47** | **6.88** | **11.78** |

Figures in parenthesis are Arc sin transformed values.

(18.30 days) and in *E. macheralis* was of 19.0 days. The highest off-spring sex ratio recorded for the parasitoids reared on the *E. macheralis* (1:1:88). However, in terms of percentage egg hatchability, *P. demoleus* was a much better host than others. The performance of this parasitoid was better on field crop pests such as *L. orbonalis, E. vittella, P. demoleus, P. xylostella* and *E. macheralis* which is a serious pest of teak, a valuable forest tree.

According to Dabhi *et al.* (2013) the performance of *Habrobracon hebetor* on stored product insects, like *Corcyra cephalonica*, was much better than on *H. armigera*, *S. litura* and *E. vittella.*

## 4.5 To construct the life table of *Bracon hebetor* on *Corcyra cephalonica* Stainton (Lepidoptera : Pyralidae).

Life table study can be very useful for designing mass rearing programs as well as deciding the timing of introduction in inoculative releases. The results on number of individuals those survived during development of *B. hebetor* Say on *C. cephalonica* Stainton revealed that maximum apparent mortality during the egg stage was 30 eggs. Highest mortality rate was registered in larval stage with 52 larvae (Table 4.21).

The number that survived from 126 eggs to adult emergence was 96 individuals. Life fecundity tables were constructed to determine the survival of female (lx) and age specific fecundity (mx). The life fecundity data presented in Table 4.19 indicated that pre-oviposition period was recorded on $11^{th}$ -$12^{th}$ day of pivotal age. Females deposited first batch of eggs on $13^{th}$ day and stopped it after $21^{st}$ day with lx values being 0.98 and 0.56, respectively. The lx decreased gradually after $14^{th}$ day of pivotal age due to adult mortality. The females contributed highest number of progeny (mx = 10.0) in the life cycle on the $13^{th}$ day of pivotal age.

The net reproductive potential (Ro) was worked as 51.27 females/ female with the mean generation time (T) of 15.96 days. The intrinsic rate of increase (rm) and finite rate of natural increase in numbers ($\lambda$) was 0.2466 and 1.2796 females/female/day, respectively. Weekly multiplication of population was calculated

**Table 4.19 Life table (for female) and age specific fecundity of *Bracon hebetor* Say on *Corcyra cephalonica* Stainton.**

| Pivotal age in days (x) | Survival of female at different age interval (lx) | Age schedule for female birth (mx) | (lxmx) | (xlxmx) |
|---|---|---|---|---|
| 0-10 | Immature stages | | | |
| 11-12 | Pre-oviposition stage | | | |
| 13 | 0.98 | 10.0 | 9.78 | 127.11 |
| 14 | 0.89 | 9.0 | 7.98 | 111.68 |
| 15 | 0.87 | 8.5 | 7.41 | 111.15 |
| 16 | 0.85 | 7.5 | 6.40 | 102.35 |
| 17 | 0.83 | 6.5 | 5.38 | 91.45 |
| 18 | 0.79 | 6.0 | 4.75 | 85.50 |
| 19 | 0.74 | 6.0 | 4.42 | 84.00 |
| 20 | 0.64 | 5.0 | 3.21 | 64.29 |
| 21 | 0.56 | 3.5 | 1.94 | 40.83 |
| | | | $Ro = \sum \text{lxmx}$ =51.27 | $\sum \text{xlxmx}$ =818.37 |

**Table 4.20. Mean length of generation, innate capacity for increase in numbers and finite rate of increase in numbers of *Bracon hebetor* Say on *Corcyra cephalonica* Stainton.**

| Population growth statistics | Formula | Calculated values |
|---|---|---|
| Net reproductive rate | $Ro = \sum \text{lxmx}$ | 51.27 |
| Mean length of generation | $Tc = \frac{\sum \text{xlxmx}}{Ro}$ | 15.96 |
| Innate capacity for increase in numbers | $rm = \frac{LogeRo}{Tc}$ | 0.2466 Females/female/day |
| Corrected generation time | $T = \frac{LogeRo}{rm}$ | 15.9655 |
| Finite rate of increase in numbers | $\lambda = \text{antilog } e^{rm}$ | 1.2796 |
| Weekly multiplication of population | $(\lambda)^9$ | 9.1974 |
| Hypothetical F2 females | $(Ro)^2$ | 2628.6129 |

**Table 4.21**. **Life table for computing life expectancy of *Bracon hebetor* Say on *Corcyra cephalonica* Stainton.**

| Life stages | Pivotal age (Days) | Number of surviving to the beginning of age interval | Number of dying during 'x' | Mortality factors | Mortality rate per hundred alive at beginning of age interval $\frac{dx.100}{lx}$ | Alive between age 'x' and 'x+1' $\frac{lx+(lx+1)}{2}$ | No. of the individuals life days beyond 'x' | Expectation of further life $\frac{Tx}{lx}\times 2$ |
|---|---|---|---|---|---|---|---|---|
| | **(*x*)** | **(*lx*)** | **(dx)** | | **(100qx)** | **(Lx)** | **(Tx)** | **(ex)** |
| **Egg** | 0-2 | 126 | 30 | Abiotic factor | 24 | 127 | 313 | 4.96 |
| **Larvae** | 2-6 | 96 | 50 | NPV | 52 | 97 | 186 | 3.88 |
| **Pupa** | 6-12 | 46 | 5 | Unknown | 11 | 47 | 89 | 3.87 |
| **Adult** | 12-20 | 41 | 0 | - | 0 | 42 | 42 | 2.05 |

9.1974 times per week. The hypothetical female's population in F2 generation was 2628.6129.The mean generation time (Tc) was 15.96 days recorded (Table 4.20).

Almost similar results were reported by Nikam and Pawar (1993) who reported the innate capacity of increase (rm) was 0.215/female per day and mean generation time (Tc) of 18.38 days but results of the weekly multiplication of population (λ) was found 52.12 times which differed from present finding with 9.1974 times weekly multiplication of population. Maafi and Hsin (2006) also found more or less similar observations on life fecundity tables when *H. hebetor* (Say) reared on *G. mellonella* (L.). They recorded finite rate of increase (lambda) 1.1640 times and mean generation time (T) 16.8 days which were much more similar to the present findings.

The above findings are in line with the findings of Farag *et al*. (2015) who found that the intrinsic rate (*rm*), the finite rate of increase ($\lambda$), the net reproductive rate ($R_0$) and the mean generation time ($T$) of *B. hebetor* reared on *C. cephalonica* with 0.1942 female per day, 1.2133 times, 30.6 and 18.09 days, respectively.

The computation of life expectancy table of *B. hebetor* Say on *C. cephalonica* Stainton (Table 5 life expectancy) clearly showed that the life expectancy of newly deposited eggs was 4.96 days. Further, it has been clearly observed that the mortality rate was comparatively high at the age of 2 to 6 days, when the expectation of further life was reduced to 2.05 days from 4.96 days in the beginning.

### 4.6 To study the viability of *Bracon hebetor* (Say) cocoons during storage as Bracocards.

In order to test the duration of storage of cocoons of *B. hebetor* "Bracocards" on black paper (6.5cm×4.5cm) by pasting liquid gum and sticking cocoons of *B. hebetor* on it. "Bracocards" thus prepared were kept for storage under refrigeration at different temperatures *viz*., 4°C, 9°C, 12°C and 27°C as control and tested for adult emergence (Fig. 4.25). Data revealed significant differences in adult emergence after cold storage among different treatments in comparison to control (Table 4.22).

### 4.6.1 At 27°C temperature

Maximum per cent of adult emergence (88.0 ± 1.79) was recorded when storage at 27°C (control) with highest with maximum male and female longevity of 6.40 ± 0.22 and 10.20 ± 0.33 days, respectively (Table 4.22 and Fig. 4.23).

### 4.6.2 At 12°C temperature

Highest per cent of adult emergence (86 ± 2.19) was recorded under one week of storage, however, further increasing the duration of storage, decreased the percentage of emerging adults. Maximum male and female adult longevity 5.6 ± 0.22 and 8.4 ± 0.36 days was registered in 3$^{rd}$ and 4$^{th}$ week of storage, respectively, however least longevity of male adults 4.8 ± 0.33 days was recorded in both 2$^{nd}$ and 6$^{th}$ week of storage similarly, minimum longevity of female adults 7.2 ± 0.33 days was noticed in 2$^{nd}$ and 6$^{th}$ both week of storage (Table 4.22 and Fig. 4.23).

### 4.6.3 At 9°C temperature

Maximum per cent adult emergence (82 ± 3.35) was recorded in one week of storage, followed by 58 ± 3.35, 46 ± 3.58, 38 ± 1.79 and 32 ± 1.79 per cent of adult emergence during 2$^{nd}$ , 3$^{rd}$ , 4$^{th}$ and 5$^{th}$ weeks of storage, respectively. Least adult emergence 26 ± 2.19 per cent was observed in 6$^{th}$ weeks of storage. Highest male adult longevity 5.2 ± 0.18 days was observed in both 4$^{th}$ and 6$^{th}$ both week and maximum female adult longevity 6.4 ± 0.36 days was registered in 5$^{th}$ week of storage (Table 4.22 and Fig. 4.23).

### 4.6.4 At 4°C temperature

In testing the duration (in weeks) of storage, six treatments of 1, 2, 3, 4, 5, and 6 weeks at 4°C temperature recorded maximum per cent of adult emergence 74 ± 4.56 was recorded in one week of storage. Nearly 30.0 per cent reduction in adult emergence was seen after two weeks of storage. The per cent adult emergence further reduced to 42 ± 1.79, 34 ± 2.19, 28 ± 3.35 and under 3, 4, 5 and 6 weeks of storage (Table 4.22 and Fig. 4.24). As far as the adult longevity of male and female was

**Table 4.22 Effect of cold storage on the percentage of adult emergence, male and female adult longevity of *B. hebetor.***

| Temp. (°C) | Time (Week) | Adult emergence % | Male adult longevity (Day) | Female adult longevity (Day) |
|---|---|---|---|---|
| **27** | Control | 88 ± 1.79 a | 6.40 ± 0.22a | 10.20 ± 0.33a |
| **12** | 1 | 86 ± 2.19 b | 5 ± 0.40abc | 7.8 ± 0.33ab |
| | 2 | 72 ± 3.35c | 4.8 ± 0.33abcd | 7.2 ± 0.33bc |
| | 3 | 58 ± 5.22d | 5.6 ± 0.22b | 7.8 ± 0.33ab |
| | 4 | 52 ± 1.79de | 5.2 ± 0.18ab | 8.4 ± 0.36b |
| | 5 | 38 ±3.35fghi | 5 ± 0.28abc | 8 ± 0.57ab |
| | 6 | 38 ± 3.5fghi | 4.8 ± 0.33 abcd | 7.2 ± 0.33bc |
| **9** | 1 | 82 ± 3.35ab | 4.6 ± 0.22 abcd | 6 ± 0.28de |
| | 2 | 58 ± 3.35d | 4.4 ± 0.36bcd | 6.2 ± 0.18cde |
| | 3 | 46 ± 3.58ef | 5.0 ± 0.28abc | 5.2 ± 0.18ef |
| | 4 | 38 ± 1.79fghi | 5.2 ± 0.18ab | 5.6 ± 0.22de |
| | 5 | 32 ± 1.79hij | 5 ± 0.28abc | 6.4 ± 0.36cd |
| | 6 | 26 ± 2.19jk | 5.2 ± 0.44ab | 6 ± 0.40de |
| **4** | 1 | 74 ± 4.56bc | 3.8 ± 0.52d | 4.4 ± 0.36fg |
| | 2 | 44 ± 2.19fg | 4.2 ± 0.52bcd | 4.2 ± 0.18fg |
| | 3 | 42 ± 1.79fgh | 3.8 ± 0.33d | 3.8 ± 0.18g |
| | 4 | 34 ± 2.19ghij | 4 ± 0.28cd | 4 ± 0.40g |
| | 5 | 28 ± 3.35ij | 5 ± 0.18abcd | 4.2 ± 0.33fg |
| | 6 | 18 ± 1.79k | 4.6 ± 0.22 abcd | 3.8 ± 0.33g |
| **CD at 5%** | | **6.07** | **1.02** | **1.03** |
| **C. V. (%)** | | **10.93** | **17.13** | **13.95** |

Note: Means followed by the same letter in a column are not significantly different at $p < 0.05$ (ANOVA followed by Tukey's test).

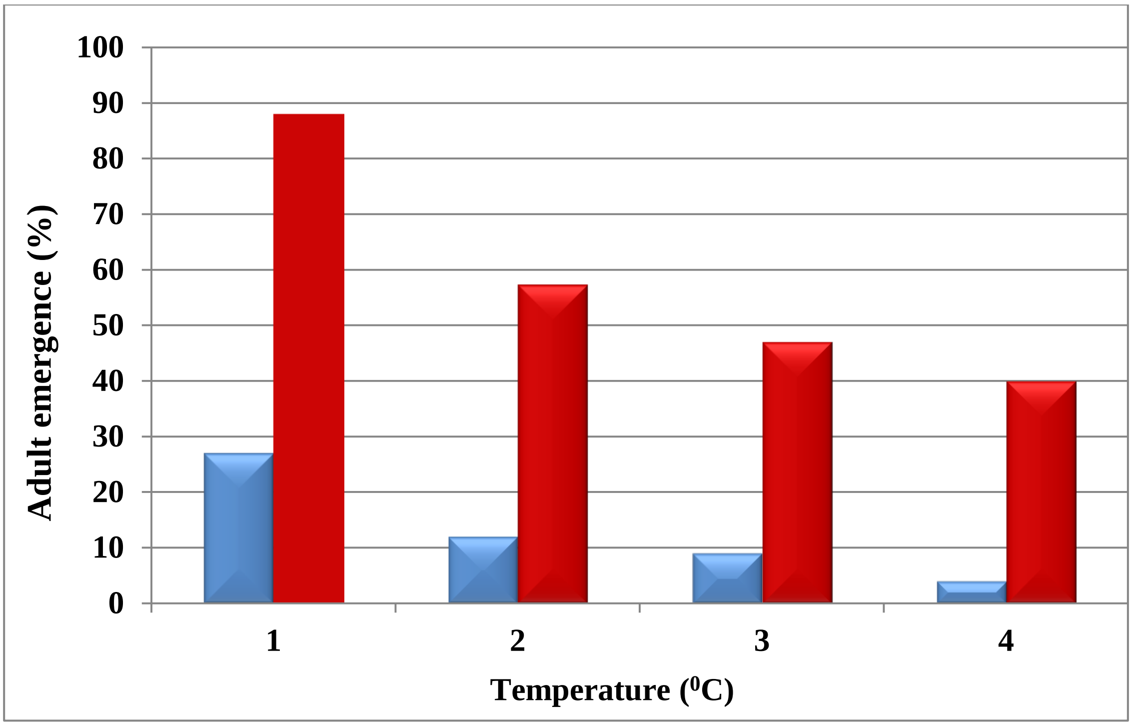



**Fig. 4.23 Effect of cold storage on the percentage of adult emergence, male and female adult longevity of *B. hebetor***

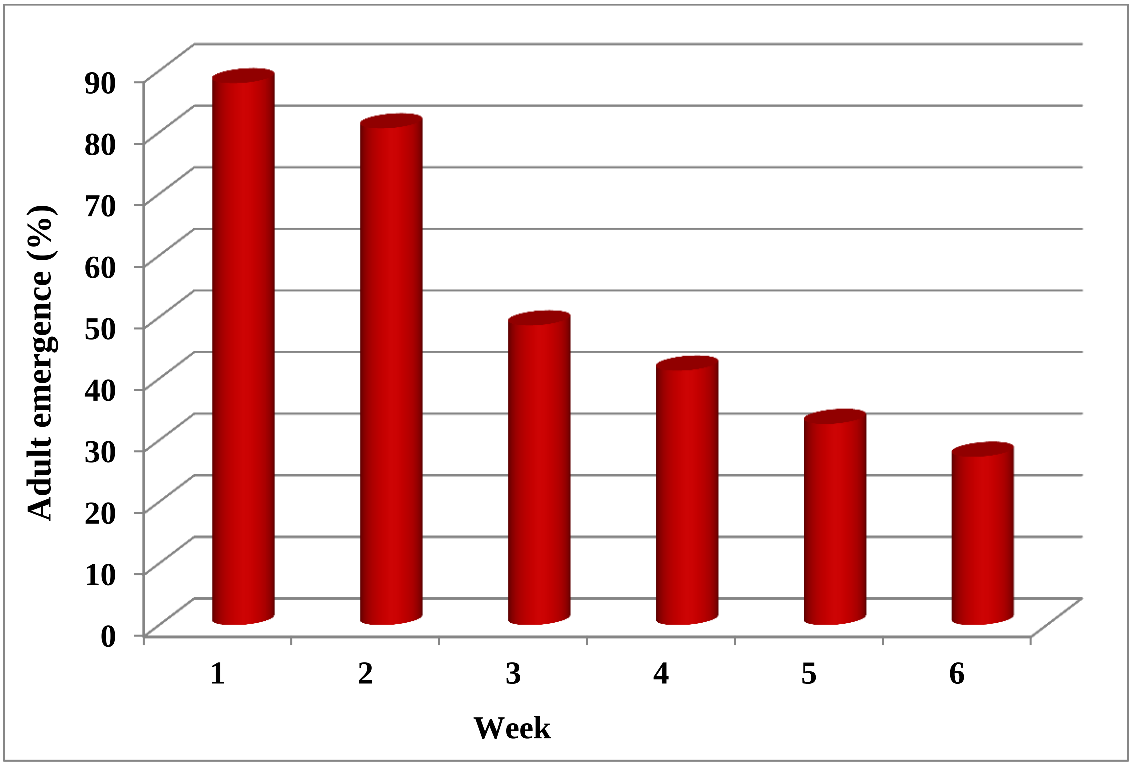
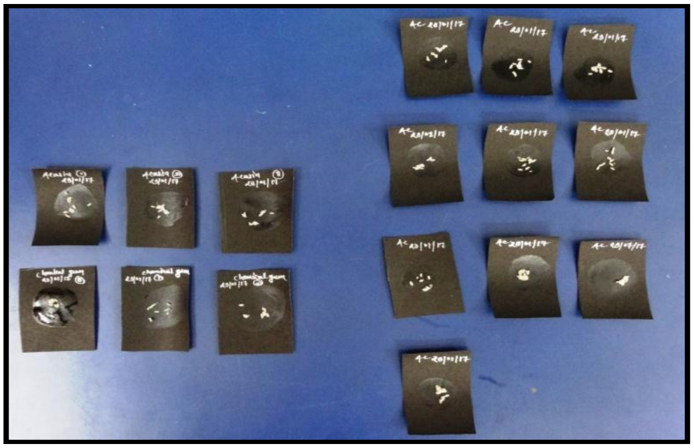



**Fig. 4.24 Effect of different period of storage (week) on the per cent emergence of adult, male and female adult longevity of *B. hebetor***



**Bracocards**

**Bracocards kept under plastic container.**

**Fig. 4.25 Container with Bracocards kept under refrigerator at different temperature**

concerned, it was significant in both, with maximum male and female longevity of 5 ± 0.18 and 4.4 ± 0.36 days, respectively.

Thus, from the above studies it can be concluded that for maximum adult emergence, "Bracocards" storage for one week is best which yielded maximum per cent of adult emergence, however emergence of adults were seen up to 6 weeks of storage, but the value decreased.

Cold storage is an appropriate way to extend the life of natural enemies such as insect parasitoids. Identification of risk factors for use in biological control and replacing it instead of chemical control is important, and therefore wasp species of genus *Bracon* have been used for controlling various pests in the past and present (Mousapour *et al*., 2013). In present findings *Bracon* pupae could be stored at $9^0$C for two weeks and at $4^0$C for one week with viability of more than 50 per cent.

These finding are in conformity with the findings of Mousapour *et al*. (2013) who tested adult emergence of *H. hebetor* at 12°C, 9°C and 4°C for a period of six weeks. Storage at 12°C showed adults emerged from the first week dropped to almost half. *H. hebetor* pupae could be stored for a week at 9°C. At 4°C, a significant reduction was caused in the adult emergence of the stored pupae and is not recommended.

Farghaly and Ragab (1993) reported the effect of low-temperature storage on pupae of *Bracon hebetor* Say. Low-temperature ($6^0$C) storage for 1, 2, 3 and 4 weeks induced 21.2, 55.6, 82.7 and 89.1% reduction in emerged adults.

Kyawt *et al*. (2004) also reported that at 15-25 $^0$C, females lived significantly longer than males. Similar findings were reported by Al Tememi *et al*. (2005) who examined the effects of cold storage period (1, 2, 3 and 4 weeks) at varying temperatures (5, 10 and 20 $^0$C). A negative relationship between the number of emerged adults (females and males) and storage period for each tested temperature was recorded. The longevity of the adult females was reduced due to low temperature for all the tested periods.

The above findings are in line with Uwais *et al*. (2006) who reported that the wasps died after 60 days of storage at low temperature. On the contrary, HaoLiang *et al*., (2013) observed that the storing of parasitoids for up to 8 weeks at 5 $^0$C would produce parasitoids that are similar to culture parasitoids.

## 4.7 To study the management of diamonback moth, *Plutella xylostella* L. on cabbage crop by release of *Bracon hebetor* Say under field conditions.

Different treatments of *Bracon hebetor* were evaluated for their efficacy against *P. xylostella* on cabbage crop by releasing Bracocards *viz*., $T_1$ Bracocard (4 cocoons), $T_2$ Bracocard (8 cocoons), $T_3$ Bracocard (10 cocoons), $T_4$ Bracocard (15 cocoons), $T_5$ Bracocard (20 cocoons) and an untreated control (Table 4.23 and Fig. 4.28).

### 4.7.1 Pretreatment observations

Observations were recorded after 2, 7, 12, 15 and 20 days after treatment. The larval population in the pretreatment observation ranged from 15.0 to 20.33 larvae per plant and non significant differences were observed among various treatments indicating more or less uniform infestation of the pest on the plants under experimentation (Table 4.23).

### 4.7.2 Two day after release

Data presented in table 4.23 showed that two days after release, the plants released with Bracocard (20 cocoons) recorded least larval population (12.33/plant) and differed significantly from rest of the treatments. Highest larval population (21.0/plant) was recorded in T2 Bracocard (8 cocoons).

### 4.7.3 Seven day after release

At seven days of release, plants with $T_3$ Bracocard (10 cocoons) recorded least larval population, which was at par with $T_5$ Bracocard (20 cocoons), but differed significantly from $T_1$ Bracocard (4 cocoons), $T_2$ Bracocard (8 cocoons) and $T_4$ Bracocard (15 cocoons). The highest larval population (20.33/ plant) was recorded in covered plant without cocoon (T6).

### 4.7.4 Twelve day after release

The minimum number of larvae (8.67/plant) was recorded with $T_5$ Bracocard (20 cocoon) which was at par with $T_4$ Bracocard (15 cocoons), $T_3$ Bracocard (10 cocoons) and $T_2$ Bracocard (8 cocoons) but differed significantly from $T_1$ Bracocard (4 cocoons) and recorded as least effective against *P. xylostella.* Highest larval population of 20.0 per plant was noticed in un-treated control.

### 4.7.5 Fifteen day after release

Fifteen days after release of Bracocard, the data in table 4.23 exhibited that, all treatments were significantly superior over untreated control and covered plant without cocoon. The plants with $T_5$ Bracocard (20 cocoons) recorded least larval population (5.0/plant). It was at par with $T_4$ Bracocard (15 cocoons), $T_2$ Bracocard (8 cocoon) but differed significantly from $T_3$ Bracocard (10 cocoons) and $T_1$ Bracocard (4 cocoons). Highest larval population of 20.67 per plant was noticed in un-treated control.

### 4.7.6 Twenty day after release

Data showed (Table 4.23) that twenty days after release, the plants with Bracocard (20 cocoons) recorded least larval population (9.33/plant) but differed significantly from rest of the treatments. The highest larval population (18.33/plant) was recorded in un-treated control.

Combined analysis indicated that the $T_5$ Bracocard (20 cocoons) was found most effective against *P. xylostella* as it recorded lowest larval population of (9.73/plant). The second best treatment was T4 (12.20 larvae /plant) followed by T3 (12.60 larvae /plant), T2 (13.47 larvae /plant) and T1 (16.27 larvae /plant) (Table 4.23 and Fig. 4.26).

Similar findings were reported by Mohanty *et al.* (2000) who released, *Bracon hebetor* in the coconut orchards infested by the black-headed caterpillar, *Opisina arenosella* (Lepidoptera : Cryptophasidae). Releases were made at fortnightly interval at 15, 20 and 25% of the pest population in four villages (Bramhagiri, Biraharekrushnapur, Batagaon and Kanthapur) in Puri district of Orissa, when

**Table 4.23 Management of diamonback moth, *Plutella xylostella* L. on cabbage crop by release of *Bracon hebetor* Say under field conditions.**

| S.N. | Treatments | Lraval population of DBM (Per plant) | | | | | | Over all mean |
|---|---|---|---|---|---|---|---|---|
| | | Pre-treatment | 2DAT | 7DAT | 12DAT | 15 DAT | 20 DAT | |
| T1 | Bracocard (4 cocoons) | 20.33 (4.61) | 20.67 (4.65)d | 19.67 (4.54)ef | 16.67 (4.19)e | 11.67 (3.54)cd | 12.67 (3.69)bc | 16.27 (4.12)bc |
| T2 | Bracocard (8 cocoons) | 19.00 (4.45) | 21.00 (4.69)de | 16.67 (4.20)cd | 11.33 (3.50)cd | 6.33 (2.69)ab | 12.00 (3.60)b | 13.47 (3.91)b |
| T3 | Bracocard (10 cocoons) | 15.00 (3.49) | 16.33 (4.16)b | 12.33 (3.64)a | 11.00 (3.46)c | 10.33 (3.36)c | 13.00 (3.74)bc | 12.60 (3.67)ab |
| T4 | Bracocard (15 cocoons) | 17.33 (4.26) | 19.00 (4.46)bc | 16.67 (4.19)c | 10.00 (3.31)ab | 5.67 (2.58)ab | 9.67 (3.26)ab | 12.20 (3.56)ab |
| T5 | Bracocard (20 cocoons) | 17.00 (4.23) | 12.33 (3.64)a | 13.33 (3.78)b | 8.67 (3.10)a | 5.00 (2.44)a | 9.33 (3.21)a | 9.73 (3.23)a |
| T6 | Covered plant without cocoons | 18.67 (4.41) | 18.67 (4.41)bc | 20.33 (4.61)g | 20.67 (4.65)fe | 20.33 (4.61)e | 15.67 (4.08)d | 19.13 (4.47)c |
| T7 | Control | 17.67 (4.31) | 17.67 (4.31)bc | 19.33 (4.50)e | 20.00 (4.58)f | 20.67 (4.65)ef | 18.33 (4.38)de | 19.20 (4.48)cd |
| | **SEm ±** | **0.18** | **0.13** | **0.11** | **0.07** | **0.10** | **0.11** | **0.16** |
| | **CD at 5%** | **NS** | **0.41** | **0.36** | **0.22** | **0.34** | **0.35** | **0.49** |
| | **C. V. (%)** | **7.43** | **5.37** | **4.81** | **3.31** | **5.54** | **5.38** | **9.66** |

Figures in parenthesis are $\sqrt{x+0.5}$ transformed values.

Same letter in a column are not significantly different.

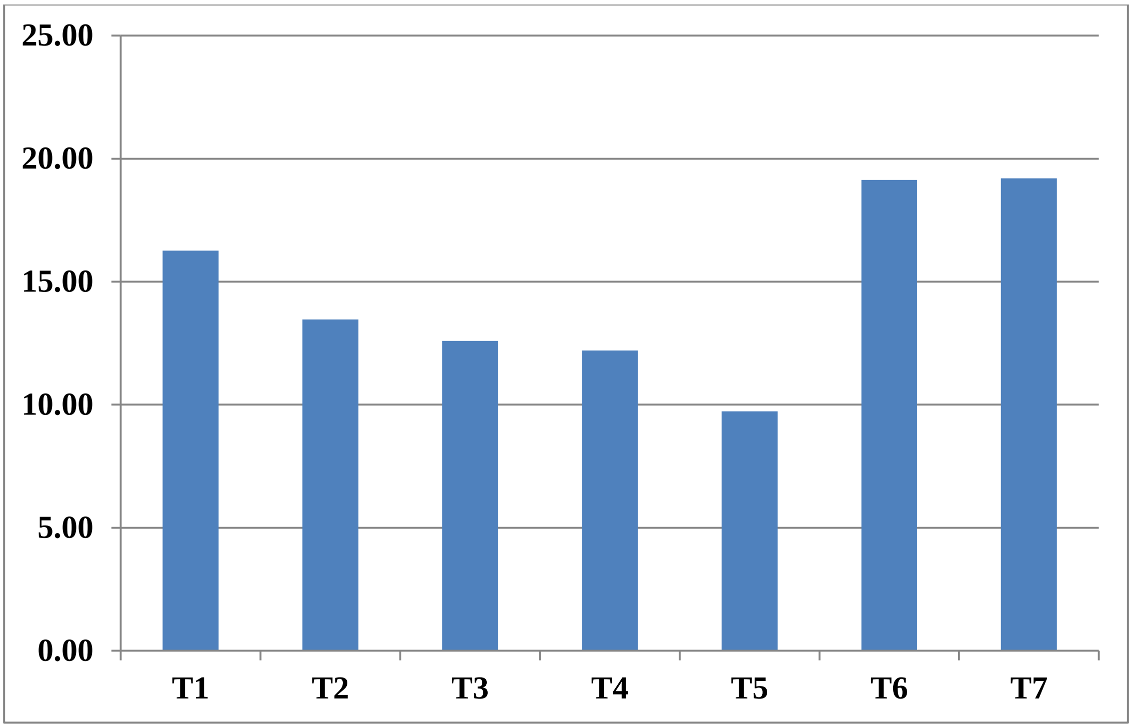



**Fig. 4.26 Management of Diamondback moth, *Plutella xylostella* L. on cabbage crop by release of *Bracon hebetor* Say under field conditions**


**Fig. 4.27 Experimental field**

**Fig. 4.28 Bracocards releasing under field.**

**Fig. 4.29 Cabbage plants covered with cage.**

**Fig. 4.30 Parasitized DBM larvae on cabbage head.**

**Fig. 4.31 *Bracon hebetor* larvae feeding on DBM larvae.**

populations were maximum during January and minimum in September. The most effective control of the pest was achieved, when the parasitoids release were 20% of the pest population. The parasitization ability and host searching ability of *B. hebetor* was higher. Mohanty *et al*. (2001) further reported that Braconids as most effective biological tool to control the vegetable crop pest brinjal shoot and fruit borer, *Leucinodes orbonalis* Guen. Shoot (0.2-10.2%) and fruit (0.1-5.1%) damage was reduced in the parasitoid released field as compared to the control. The percent reduction in shoot and fruit damage gradually increased with the number of releases along with the age of the plants.

Rajamanickam *et al*. (2002) made inundative release of larval parasitoid *B. brevicornis* to manage coconut leaf eating caterpillar, *Opisina arenosella* at recommended dose at 21 days interval, estimated mean pest population/palm significantly reduced from 785.60 to 210.50 at 21 days. The above three findings are similar in showing the reduction in larval populations of *P. xylostella* on cabbage at different doses.

# CHAPTER - V
# SUMMARY AND CONCLUSION

The experiment entitled "Studies on the host variability and ovipositional behaviour of larval ecto-parasitoid, *Bracon* spp. (Hymenoptera : Braconidae) at Raipur, Chhattisgarh" was under taken at the Biocontrol laboratory, Department of Entomology, College of Agriculture, IGKV Raipur (C.G.) during 2015-16 and 2016-17.

To collect Braconids and other parasitoids survey work was conducted on cereals like paddy and maize, legumes like pigeon pea and chickpea, vegetables like brinjal, tomato, cabbage and okra and fruits like ber, guava, sapota and mango ecosystem. Eighteen species of *Bracon* and other parasitoids were noticed on various crop ecosystem. Highest number of parasitoids were recorded in paddy, maize and pigeon pea with four species of parasitoids namely *Bracon* sp., *Bracon hebetor* Say, *Cotesia flavipes* Cameron and twelve unknown species. *Bracon brevicornis* and *Goniozus* spp. were recorded for the first time in cabbage and sapota crop ecosystem, respectively. Eighteen species of parasitoid wasp *viz.*, *Cotesia flavipes*, *Elasmus* sp., *Bracon* spp, *Bracon hebetor* Say, *Bracon brevicornis* (Wesmael), *Goniozus* sp. and twelve species were unidentified. The most dominant parasitoids in decreasing order are *Cotesia flavipes* (32%), *Bracon* sp. (20%), *Bracon hebetor* (7%),*Goniozus* sp.(7%) and *Bracon brevicornis* (2%).

Preference study of *Bracon hebetor* on *Helicoverpa armigera* Hub. feeding on different hosts raveled that the shortest life cycle (egg to adult) of *Bracon hebetor* male was recorded in pea reared larvae with 14.81 days and longest developmental period on chick pea reared larvae of 15.80 days. Minimum and maximum developmental days of female was recorded 17.06 and 18.10 days in pea and pigeon pea reared larvae, respectively. The minimum adult longevity of male (4.10 days) was found in chickpea reared larvae whereas the maximum adult longevity of male (5.40 days) was found in okra reared larvae. The minimum adult longevity of female (5.60

days) was found in chickpea reared larvae, maximum adult longevity of female (7.90 days) was found in pigeon pea reared larvae. Longevity of female was longer than male.

Two species of host larvae with second and fourth instar were evaluated for ovipositional preference of *Bracon* spp. Highest fecundity of 37.75 eggs was recorded on *H. armigera* ($4^{th}$ instar) followed by 18.50, 17.50 and 14.0 eggs on *H. armigera* ($2^{nd}$ instar), *S. litura* ($4^{th}$ instar) and *S. litura* ($2^{nd}$ instar), respectively. The lowest egg period (1.13 days) was registered with *S. litura* ($4^{th}$ instar) followed by *S. litura* ($2^{nd}$ instar) and *H. armigera* ($4^{th}$ instar) with 1.50 days for both insects. Maximum time (4.69 days) was required to complete larval duration in case of *H. armigera* ($4^{th}$ instar) in comparison to rest of the host larvae used. Lowest larval duration (3.75 days) was registered in case of *S. litura* ($4^{th}$ instar). Shorter pupal period was exhibited in these three larval hosts over rest of the host larvae used, except *H. armigera* ($4^{th}$ instar) which recorded longest pupal period of 5.63 days. Least duration of life-cycle of female was found in *S. litura* ($4^{th}$ instar) with 17.78 days. Shortest duration of male life-cycle was recorded in *S. litura* ($4^{th}$ instar) with the period of 14.72 days. The Sex ratio study on *B. hebetor*, revealed that males dominated on both hosts.

All six host species tested were acceptable to the *Bracon hebetor* females for parasitism and oviposition. The highest fecundity (112.80 eggs/female) was observed on the larvae of the rice meal moth, *Corcyra cephalonica*, however, lowest fecundity (22.80eggs/female) was observed on the larvae of *Plutella xylostella*. Longest larval period recorded for those that developed on *P. demoleus* (4.35 days) and shortest on *P. xylostella* (3.05 days). Shortest pupal period recorded on *P. xylostella* (4.30 days) and the longest on *P. demoleus* (5.42 days). Total developmental periods of adult male from egg to adult was non significantly differed in all the treatments, however, shortest life cycle (18.30 days) of female parasitoid was recorded in *P. xylostella*. The sex ratio was greatest for those reared on *E. macheralis* (1:1.88) and lowest for those reared on *P. xylostella* (1:1.13).

Life table study can be very useful for designing mass rearing programs as well as deciding the timing of introduction in inoculative releases. In the present study maximum apparent mortality during the egg stage was 30 eggs. Highest mortality rate was registered in larval stage with 52 larvae. The number that survived from 126 eggs to adult emergence was 96 individuals. Females deposited first batch of eggs on 13$^{th}$ day and stopped it after 21$^{st}$ day with lx values being 0.98 and 0.56, respectively. The lx decreased gradually after 14$^{th}$ day of pivotal age due to adult mortality. The females contributed highest number of progeny (mx = 10.0) in the life cycle on the 13$^{th}$ day of pivotal age.

The net reproductive potential (Ro) was worked as 51.27 females/ female with the mean generation time (T) of 15.96 days. The intrinsic rate of increase (rm) and finite rate of natural increase in numbers (λ) was 0.2466 and 1.2796 females/female/day, respectively. Weekly multiplication of population was 9.1974 times per week. The hypothetical female's population in F2 generation was 2628.6129.The mean generation time (Tc) was 15.96 days recorded.

In order to test the duration of storage of cocoons of *B. hebetor* "Bracocards" kept under refrigeration at different temperatures *viz*., 4°C, 9°C, 12°C and 27°C as control and tested for adult emergence. Maximum per cent of adult emergence (88.0 ± 1.79) was recorded when storage at 27°C (control) with highest with maximum male and female longevity of 6.40 ± 0.22 and 10.20 ± 0.33 days, respectively.

Adult emergence (86 ± 2.19 %) was recorded at 12 °C under one week of storage however, maximum male and female adult longevity 5.6 ± 0.22 and 8.4 ± 0.36 days was registered in 3$^{rd}$ and 4$^{th}$ week of storage. At 9°C temperature maximum per cent of adult emergence (82 ± 3.35) was recorded in one week of storage. Least adult emergence 26 ± 2.19 per cent was observed in 6$^{th}$ weeks of storage. Highest male adult longevity 5.2 ± 0.18 days was observed in both 4$^{th}$ and 6$^{th}$ both week of storage and maximum female adult longevity 6.4 ± 0.36 days was registered in 5$^{th}$ week of storage. Similarly, at 4°C temperature maximum per cent of adult emergence 74 ±

4.56 was recorded in one week of storage, however, maximum male and female adult longevity at 4°C of *B. hebetor* last for 5 ± 0.18 and 4.4 ± 0.36 days, respectively.

Different treatments of *Bracon hebetor* were evaluated for their efficacy against *P. xylostella* on cabbage crop by releasing Bracocards *viz*., $T_1$ Bracocard (4 cocoons), $T_2$ Bracocard (8 cocoons), $T_3$ Bracocard (10 cocoons), $T_4$ Bracocard (15 cocoons), $T_5$ Bracocard (20 cocoons) and an untreated control. Among the treatments $T_5$ Bracocard (20 cocoons) was found most effective against *P. xylostella* as it recorded lowest larval population of (9.73/plant). The second best treatment was T4 (12.20 larvae /plant) followed by T3 (12.60 larvae /plant), T2 (13.47 larvae /plant) and T1 (16.27 larvae /plant).

**CONCLUSION:**

- Survey work contributes to the knowledge of the entomological fauna occurring in the plain regions of Chhattisgarh. Local species of Braconids existing in all crop ecosystem. The most dominant parasitoids in decreasing order are *Cotesia flavipes, Bracon* sp., *Bracon hebetor,Goniozus* sp. and *Bracon brevicornis*.
- Pigeon pea reared *H. armigera* larvae was the most preferred host of *B. hebetor* in terms of fecundity, egg hatching, eclosion, viability percentage and sex ratio.
- *H. armigera* ($4^{th}$ instar) larvae recorded most oviposition preferable host for *B. hebetor* with highest fecundity, egg hatching, eclosion, viability percentage and sex ratio.
- *Corcyra cephalonica* found to be the best host for laboratory mass rearing of *B. hebetor* with highest fecundity followed by *Eutectona macheralis, Leucinodes orbonalis, Earias vittella*, *Papilio demoleus* and *Plutella xylostella*.
- Life table study revealed that maximum mortality apparent during the larval stage followed by egg and pupa stage. Abiotic factor, NPV and unknown mortality factor recorded for eggs, larvae and pupa stage, respectively.

- Viability of *Bracon hebetor* (Say) cocoons during storage as Bracocards revealed that the storage for one week is best which yielded maximum per cent of adult emergence, however emergence of adults were seen up to 6 weeks of storage, but the value decreased.
- Bracocard (20 cocoons) was found most effective against *P. xylostella* as it recorded lowest larval population. The second best treatment was Bracocard (15 cocoons), Bracocard (10 cocoons), Bracocard (8 cocoons) and Bracocard (4 cocoons).

**SUGGESTIONS FOR FUTURE RESEARCH:**

- Studies on biology of *Bracon hebetor* for minimum ten generation.
- Survey on naturally occurring *Bracon sp.* in forest area to know the species richness.
- Test the preference of Bracon on different weight of *Corcyra* larvae.
- *Corcyra* larvae reared from different host can also be tested for *B. hebetor* with special reference to sex ratio.
- Test the ovipositional and parasitisation prefence of *Bracon* on different instars of *Corcyra* larvae reared from a common host can be tested.
- Studies on life cycle of *Bracon* on different types of containers with sandwich method.
- Effect of host larvae on cocoon size and shape of male and female *Bracon* can be tested.
- Life table of *Bracon* on different types of larvae can also be studies.

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# RESUME

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