STANDARDIZATION OF MASS REARING TECHNIQUE AND FIELD EVALUATION OF PHEROMONE OF SHOOT AND FRUIT BORER, *Conogethes* spp. (LEPIDOPTERA: CRAMBIDAE) ON SELECTED HOST PLANTS

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PALB 4009

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

UNIVERSITY OF AGRICULTURAL SCIENCES

GKVK, BENGALURU-560 065

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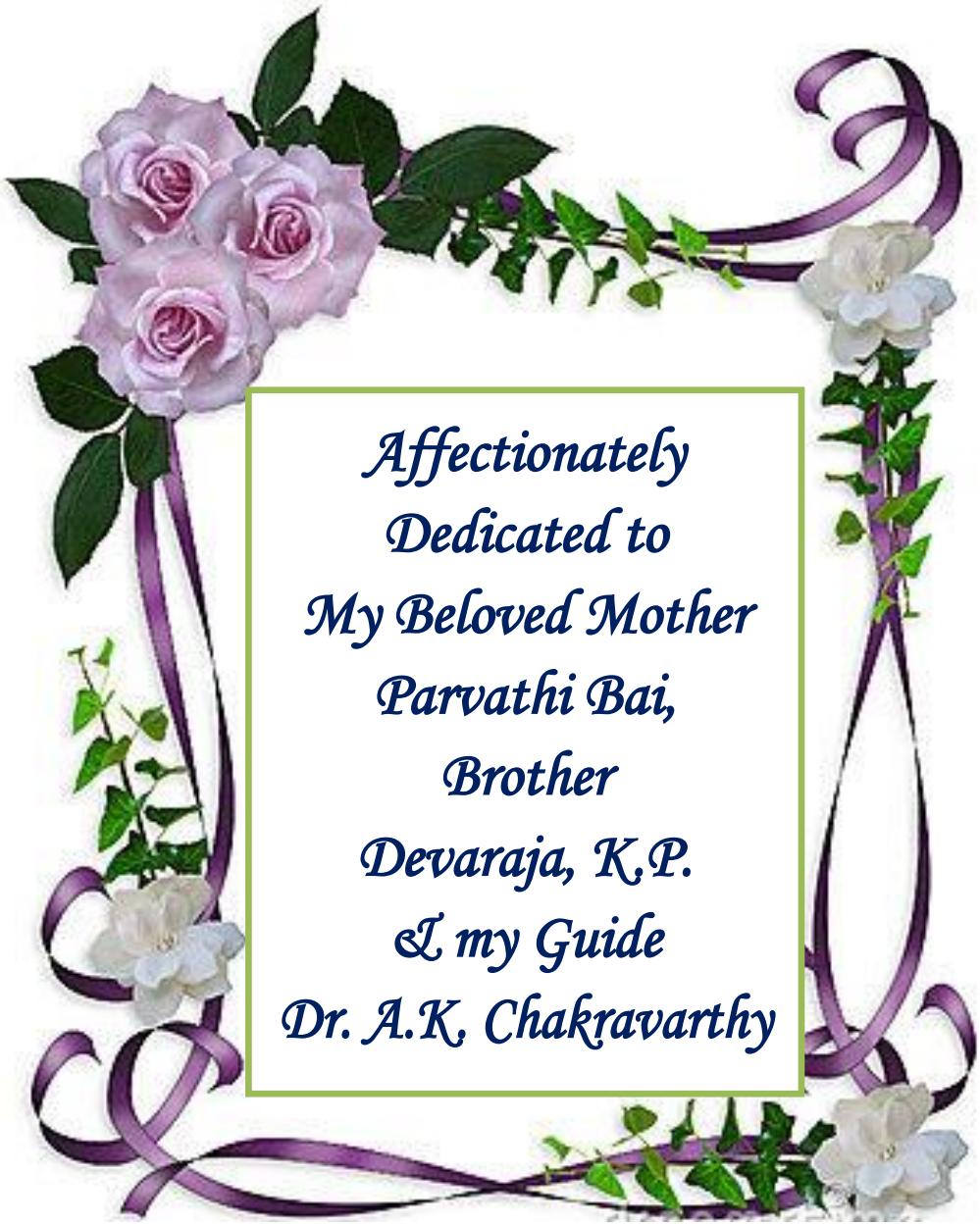
Affectionately
Dedicated to
My Beloved Mother
Parvathi Bai,
Brother
Devaraja, K.P.
& my Guide
Dr. A.K. Chakravarthy

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY
UNIVERSITY OF AGRICULTURAL SCIENCES
BENGALURU - 560 065

CERTIFICATE

This is to certify that the thesis entitled **"STANDARDIZATION OF MASS REARING TECHNIQUE AND FIELD EVALUATION OF PHEROMONE OF SHOOT AND FRUIT BORER, *Conogethes* spp. (LEPIDOPTERA: CRAMBIDAE) ON SELECTED HOST PLANTS"** submitted in partial fulfillment of the requirements for the award of degree **DOCTOR OF PHILOSOPHY** in **AGRICULTURAL ENTOMOLOGY** to the University of Agricultural Sciences, Bengaluru, is a record of *bona-fide* research work done by **Mr. KUMAR, K. P., ID No. PALB 4009** during the period of his study in this University, under my guidance and supervision and the thesis has not been previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

A.K. Cha

BENGALURU
DECEMBER, 2018

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(R. KRISHNA MANOHAR)

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*"We are responsible for what we are, and whatever we wish ourselves to be, we have the power to make ourselves. If what we are now has been the result of our own past actions, it certainly follows that whatever we wish to be in future can be produced by our present actions; so we have to know how to act"- **Swami Vivekananda.***

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December, 2018 ***KUMAR, K. P.***

Standardization of mass rearing technique and field evaluation of pheromone of shoot and fruit borer, *Conogethes* spp. (Lepidoptera: Crambidae) on select host plants

KUMAR, K. P.

ABSTRACT

Studies conducted on standardization of mass rearing technique and field evaluation of pheromone of shoot and capsule borer, *Conogethes* spp. (Lepidoptera: Crambidae) on selected host plants brought out striking differences in the pest species. The studies on artificial diet clearly showed that the diets incorporated with castor and cardamom powders were suitable for growth and development of *C. punctiferalis* and *C. sahyadriensis*, respectively. Further studies on standardization of other ingredients in the diet like Casein 35g/ml, Vit-E capsule (1g/ml), Sorbic acid (1g/ml), Methyl parahydroxy benzoate (2g/ml) and Streptomycin sulphate (0.5g/ml) recorded higher percentage of fecundity, survivability and pupal weight of *C. punctiferalis* and *C. sahyadriensis.* Field observations on seasonal incidence of *C. punctiferalis* in castor fields revealed that maximum infestation occurred during November to December. The incidence of *C. sahyadriensis* in cardamom plantations was maximum cardamom shoot during May and in capsule during October to November which coincided with tillering and capsule formation. Similarly, in ginger plantations results revealed that maximum borer infestation occurred during September to October. The influence of abiotic factors showed that temperature and relative humidity played a major role in the incidence of these borers in cardamom, castor and ginger. Studies on standardization of trapping technique indicated that all the traps baited with pheromone lures had significantly higher catches over the traps without pheromone lures. Among four types of traps (delta, water, funnel and cross-vane trap) tested, delta trap with lure (contained (*E*)-10-hexadecenal (E10-16: Ald), (*Z*)-10-hexadecenal (Z10-16: Ald) and hexadecenal (16: Ald) at 100:8:16) proved the most effective for trapping males of *C. punctiferalis* moths compared to other traps. Further studies on colour and height of traps revealed that yellow delta traps installed at the crop canopy level trapped maximum moths of *C. punctiferalis.*

December, 2018

Department of Agricultural Entomology
UAS, GKVK, Bengaluru-65

A. K. CHAKRAVARTHY
(Major Advisor)

ಕಾಂಡ ಮತ್ತು ಕಾಯಿ ಕೊರಕ, *ಕೋನೋಗೆಥೆಸ್* ಎಸ್ಪಿಪಿ. (ಲೆಪಿಡೋಪ್ಟೆರಾ: ಕ್ರ್ಯಾಂಬಿಡೆ) ಕೀಟಗಳ ಸಾಮೂಹಿಕ ಪಾಲನೆ ತಂತ್ರದ ಪ್ರಮಾಣೀಕರಣ ಮತ್ತು ಆಯ್ದ ಅತಿಥೇಯ ಸಸ್ಯಗಳ ಕ್ಷೇತ್ರದಲ್ಲಿ ಮೋಹಕಾರಕಗಳ ಮೌಲ್ಯಮಾಪನದ ಅಧ್ಯಯನ"

ಕುಮಾರ, ಕೆ. ಪಿ.

ಪ್ರಬಂಧದ ಸಾರಾಂಶ

ಸಾಮೂಹಿಕ ಪಾಲನೆ ತಂತ್ರದ ಪ್ರಮಾಣೀಕರಣ ಮತ್ತು ಮೋಹಕಾರಕ ಘಟಕಗಳ ಮೌಲ್ಯಮಾಪನವನ್ನು ಆಯ್ದ ಅತಿಥೇಯ ಸಸ್ಯಗಳಲ್ಲಿ ಅಧ್ಯಯನ ನಡಸಿದಾಗ ಕೋನೋಗೆಥೆಸ್ ಕೀಟ ಜಾತಿಗಳಲ್ಲಿ ಗಮನಾರ್ಹ ವ್ಯತ್ಯಾಸ ಕಂಡು ಬಂದಿದೆ. ಹರಳೆ ಮತ್ತು ಏಲಕ್ಕಿ ಪುಡಿಗಳೊಂದಿಗೆ ಸೇರಿಸಲಾದ ಆಹಾರಕ್ರಮಗಳು ಅನುಕ್ರಮವಾಗಿ *ಕೋನೋಗೆಥೆಸ್ ಪಂಕ್ಟಿಫೆರಾಲಿಸ್* ಮತ್ತು *ಕೋನೋಗೆಥೆಸ್ ಸಹ್ಯಾದ್ರಿಯೆನ್ಸಿಸ್* ಬೆಳವಣಿಗೆ ಮತ್ತು ಅಭಿವೃದ್ಧಿಗೆ ಸೂಕ್ತವಾದವು ಎಂದು ಕೃತಕ ಆಹಾರ ಅಧ್ಯಯನಗಳಲ್ಲಿ ಸ್ಪಷ್ಟವಾಗಿ ಸಾಬಿತುಪಡಿಸಲಾಗಿದೆ. ಕೆಸಿನ್ (35 ಗ್ರಾಂ/ಮಿಲೀ), ವಿಟಾಮಿನ್–ಇ (1 ಗ್ರಾಂ/ಮಿಲೀ), ಸೊರ್ಬಿಕ್ ಆಸಿಡ್ (1 ಗ್ರಾಂ/ಮಿಲೀ), ಮೀಥೈಲ್ ಪ್ಯಾರಾಹೈಡ್ರಾಕ್ಸಿ ಬೆಂಜೊಯೇಟ್ (2 ಗ್ರಾಂ/ಮಿಲೀ), ಮತ್ತು ಸ್ಟ್ರೆಪ್ಟೊಮೈಸಿನ್ ಸಲ್ಫೇಟ್ (0.5 ಗ್ರಾಂ/ಮಿ.ಲೀ) ನಂತಹ ಇತರ ಪದಾರ್ಥಗಳನ್ನು ಹೊಂದಿದ ಆಹಾರವನ್ನು ತಿಂದ ಕೀಟಗಳಲ್ಲಿ ಹೆಚ್ಚಿನ ಶೇಕಡಾವಾರು ಮೃದುತ್ವ, ಬದುಕುಳಿಯುವಿಕೆ ಮತ್ತು *ಕೋನೋಗೆಥೆಸ್ ಪಂಕ್ಟಿಫೆರಾಲಿಸ್* ಮತ್ತು *ಕೋನೋಗೆಥೆಸ್ ಸಹ್ಯಾದ್ರಿಯೆನ್ಸಿಸ್* ಕೋಶಗಳ ಗರಿಷ್ಠ ತೂಕವನ್ನು ದಾಖಲಿಸಿವೆ. ಹರಳೆ ಬೆಳೆಯಲ್ಲಿ *ಕೋನೋಗೆಥೆಸ್ ಪಂಕ್ಟಿಫೆರಾಲಿಸ್‌ನ* ಋತುಮಾನದ ಘಟನೆಗಳ ಕುರಿತಾದ ಕ್ಷೇತ್ರದ ಅವಲೋಕನವು ನವಂಬರ್ ನಿಂದ ಡಿಸಂಬರಗಿನ ಗರಿಷ್ಠ ಮುತ್ತಿಕೊಳ್ಳುವಿಕೆ ಸಂಬವಿಸಿದೆ ಎಂದು ದೃಢಪಡಿಸಿದೆ. ಏಲಕ್ಕಿ ನೆಡತೋಪುಗಳಲ್ಲಿ *ಕೋನೋಗೆಥೆಸ್ ಸಹ್ಯಾದ್ರಿಯೆನ್ಸಿಸ್* ಸಂಭವಿಸುವಿಕೆಯು ಮೇ ತಿಂಗಳಲ್ಲಿ ಅದು ಏಲಕ್ಕಿ ಚಿಗುರು ಹಂತದಲ್ಲಿ ಮತ್ತು ಕೋಶಾವರಣ ಹಂತದಲ್ಲಿ ಅಕ್ಟೋಬರ್ ನಿಂದ ನವಂಬರ್‌ವರೆಗಿನ ಅವಧಿಯಲ್ಲಿ ಗರಿಷ್ಠ ಮುತ್ತಿಕೊಂಡಿತ್ತು ಎಂದು ಋತುಮಾನ ಘಟನೆಗಳ ಅಧ್ಯಯನದಲ್ಲಿ ಕಂಡು ಬಂದಿದೆ, ಈ ಸಂಭವಿಸುವಿಕೆಯು ಕಾಂಡ ಮತ್ತು ಕಾಯಿ ರಚನೆಯೊಂದಿಗೆ ಹೊಂದಿಕೊಂಡಿರುತ್ತದೆ. ಅಂತೆಯೇ ಶುಂಠಿ ತೋಟಗಳಲ್ಲಿ ಸೆಪ್ಟಂಬರ ನಿಂದ ಅಕ್ಟೋಬರ್ ವರಗೆ *ಕೋನೋಗೆಥೆಸ್ ಸಹ್ಯಾದ್ರಿಯೆನ್ಸಿಸ್* ನ ಗರಿಷ್ಠ ಬಾಧೆ ಕಂಡು ಬಂದಿದೆ ಎಂದು ಫಲಿತಾಂಶಗಳು ಬಹಿರಂಗಪಡಿಸಿದೆ. ಅಜೈವಿಕ ಅಂಶಗಳಾದ ತಾಪಮಾನ ಮತ್ತು ಸಾಪೇಕ್ಷ ಆರ್ದ್ರತೆಯು ಏಲಕ್ಕಿ, ಹರಳು ಮತ್ತು ಶುಂಠಿ ಬೆಳೆಗಳಲ್ಲಿ ಈ ಕಾಂಡ ಮತ್ತು ಕಾಯಿ ಕೊರಕಗಳ ಬಾಧೆಯಲ್ಲಿ ಪ್ರಮುಖ ಪಾತ್ರವಹಿಸುತ್ತದೆಯೆಂದು ದಾಖಲಿಸಿದೆ. ಬಲೆಗೆ ಬೀಳಿಸುವ ತಂತ್ರದ ಪ್ರಮಾಣೀಕರಣದ ಅಧ್ಯಯನಗಳು ಮೋಹಕಾರಕ ಇರುವ ಎಲ್ಲಾ ಬಲೆಗಳು ಪತಂಗಗಳನ್ನು ಸೆರೆಹಿಡಿಯುತ್ತವೆ, ಮತ್ತು ಮೋಹಕಾರಕ ಇಲ್ಲದ ಬಲೆಗಳು ಸೆರೆಹಿಡಿಯುದಿಲ್ಲ ಎಂದು ಸೂಚಿಸಿದೆ. ಪರೀಕ್ಷೆಗೊಳಪಟ್ಟ ನಾಲ್ಕು ರೀತಿಯ ಬಲೆಗಳಲ್ಲಿ (ಡೆಲ್ಟಾ, ನೀರು, ಕೊಳವೆಯ ಮತ್ತು ಕ್ರಾಸ್‌ವೇನ್ ಬಲೆ) ಡೆಲ್ಟಾ ಮೋಹಕ ಬಲೆಯು (ಒಳಗೊಂಡಿರುವ (E)–10–ಹೆಕ್ಸಾಡೆಸೆನಲ್ (E10-16:Ald), (Z)–10–ಹೆಕ್ಸಾಡೆಸೆನಲ್ (Z10-16:Ald) ಮತ್ತು ಹೆಕ್ಸಾಡೆಸೆನಲ್ (16:Ald) ನಲ್ಲಿ 100:8:16) ಇತರೆ ಬಲೆಗಳಿಗೆ ಹೋಲಿಸಿದರೆ ಗಂಡು *ಕೋನೋಗೆಥೆಸ್ ಪಂಕ್ಟಿಫೆರಾಲಿಸ್* ಪತಂಗಗಳನ್ನು ಪತ್ತೆ ಹಚ್ಚುವುದಕ್ಕೆ ಹೆಚ್ಚು ಪರಿಣಾಮಕಾರಿಯಾಗಿದೆ ಎಂದು ಸಾಬಿತಾಗಿದೆ. ಬಲೆಗಳ ಬಣ್ಣ ಮತ್ತು ಎತ್ತರದ ಬಗೆಗಿನ ಅಧ್ಯಾಯನದಲ್ಲಿ, ಬೆಳೆಯ ಮೇಲಾವರಣ ಮಟ್ಟದಲ್ಲಿ ಸ್ಥಾಪಿಸಲಾದ ಹಳದಿ ಬಣ್ಣದ ಡಲ್ಟಾ ಮೋಹಕ ಬಲೆಗಳು ಗರಿಷ್ಠ ಗಂಡು ಪತಂಗಗಳನ್ನು ಸೆರೆಹಿಡಿಯಲ್ಪಟ್ಟಿದೆ ಎಂದು ಕಂಡುಬಂದಿದೆ.

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ಕೀಟಶಾಸ್ತ್ರ ವಿಭಾಗ, ಕೃಷಿ ಕಾಲೇಜು
ಜಿ.ಕೆ.ವಿ.ಕೆ. ಬೆಂಗಳೂರು–560065

ಎ. ಕೆ. ಚಕ್ರವರ್ತಿ
(ಪ್ರಧಾನ ಮಾರ್ಗದರ್ಶಕರು)

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I INTRODUCTION

Spices are high-value products extensively used in several culinary preparations all over the world for incurring flavour and taste. Many spices are also increasingly being valued as functional foods for nutraceutical properties. Over 100 species of plants yield spices and among them zingiberaeceous species such as cardamom (*Elettaria cardamomum* Maton), ginger (*Zingiber officinale* Rosc.) and turmeric (*Curcuma longa* L.), account for a major share in production and trade of spices in the world. Ginger and turmeric are herbaceous plants native to South Asia and their dried rhizomes yield the spice of commerce. India and China are leading producers of ginger in the world where as India is a leading producer of turmeric in the world.

Cardamom (Zingiberaceae) is a large perennial, pungent aromatic herbaceous, rhizomatous monocot grown as a major spice crop in hill areas of Karnataka, Tamil Nadu and Kerala and is called as the "Queen of spices". Guatemala and India are leading producers of cardamom in the world. Cardamom based on the cultivar and method of curing the capsule is also referred to as green cardamom, black cardamom, brown cardamom, red cardamom or white cardamom traditionally cultivated in valleys of moist evergreen forests, Western Ghats, South India (Thimmarayappa, 1999).

Castor, *Ricinus communis* L. (Euphorbiaceae) is a non-edible oilseed crop grown as major dry land crop in India. It is indigenous to the South eastern Mediterranean basin, East Africa and India. It is widespread throughout tropical region because of the commercial importance of oil extracted from seeds having wide-spread industrial uses like lubricants, paints, pharmaceuticals and aeronautics. Castor-seed products are uniquely important in view of their ability to get degraded and having eco-friendly properties with multiple utility. Thus, the world demand for castor oil is increasing at the rate of about 3-5 per cent per annum. India dominates the castor oil exports market to most of the industrialized nations (Anonymous, 2011).

Among the factors affecting the yield and quality of cardamom, ginger, turmeric and castor, the damage caused by insect pests is considered as a major constraint for successful cultivation. Among the insect pests, shoot and capsule borer *Conogethes* spp

(Crambidae: Lepidoptera) has become a major production constraint infesting shoots, succulent panicles, racemes, immature capsules and stem causing typical "dead heart". Moreover, the late instar larvae thriving inside the stem is inaccessible to the insecticidal action (Josephrajkumar *et al*., 2007) and is also called as yellow peach moth or cardamom or castor shoot and capsule borer/ginger shoot borer. It is distributed widely from Australia to most areas of Asia including China (Wang *et al*., 2006; Inoue and Yamanaka, 2006 and Lu, *et al*., 2010). Larvae of *Conogethes* species are polyphagous infesting more than 120 wild and cultivated plants *viz*., peach, apple, pine trees, chestnut, durian, citrus, papaya, cardamom, ginger, eggplant, sunflower, maize and forestry plants (Sekiguchi, 1974; Lu, *et al*. 2010).

The castor shoot and capsule borer damage was 16 to 72 per cent in Maharashtra with peak damage to panicles and capsules occurring in September and November. Withering of castor spike ranged from 3 to 8 per cent. The per cent damaged seeds ranged from 27 to 46, averaging 34.7 per cent (Bilapate and Talati, 1977).

Shoot and capsule borer infests shoot, stem, panicles, flowers and capsule of cardamom and causes yield loss of 70 to 80 per cent (Varadarasan, 2001). However, in ginger and turmeric, the shoot borer causes yield loss up to 50 per cent (Senthil *et al.*, 2015). Therefore, there is a need to study the basic aspects in detail on shoot borer, *Conogethes* sp. for effective management. Farmers indiscriminately apply insecticides conventionally. This results in higher costs and low-quality produce. This also causes adverse effects on beneficial arthropods and deteriorating environmental quality. Cardamom is cultivated in evergreen tropical forests and hence, conservation of biodiversity is crucial.

Despite efforts to manage this pest effectively (Waterhouse 1993; Chakravarthy and Thyagaraj, 1999; Rajabaskar and Ragupathy, 2012; Ganesha *et al.*, 2013; Du *et al.*, 2015), basic studies on bioecology of the shoot and fruit borer by mass rearing are lacking. So, currently it continues to be one of the most severe pests on diversified host plants. One of the reasons for failure to manage this pest may be that comprehensive studies on its physiology and toxicology are lacking. This is because a large number of specimens of determined age, sex, and weight at a given time are not available. Currently whole genome

sequences of several insects are being worked out for which, the three-dimensional structures of proteins are required. This step necessitates mass production of insects (Kobayashi *et al.,* 2008). Insect rearing is a prerequisite to ensure the continuous supply of larval and pupal stages of the insects for several research works. It is convenient to rear them on a suitable artificial or semi-syntetic diet rather than on natural diet. Because of non-availability of host plants continuously and high rate of mortality due to increased handling of larvae, there is a risk of introduced pathogens on host plant material. Hence, for any research, artificial or semi-synthetic diets are preferred that can reduce handling and disease incidence problem to a large extent. Species of *Conogethes* have often been misidentified (Chakravarthy *et al.,* 2015) due to cryptic species complex. Answers to many of the pending questions will be facilitated by mass rearing the *Conogethes* species. Du *et al.* (2012) and (2015) developed an artificial diet for *C. punctiferalis*.

The differences in habitat of castor and cardamom and morphological characters of *Conogethes* moths infesting both crops, elicits a doubt that the *Conogethes* populations infesting castor and spice crops may be different. Newer compounds, spinetoram and cyazypyr have shown promise when selectively applied at appropriate time and dose. Timely harvests, clean cultivation, encouragement of pollinators and natural enemies, fruit thinning and bagging, balanced nutrition can greatly help in managing the *Conogethes* populations. Botanical formulations and mass trapping of moths by pheromones traps can lead to realistic management of the pest resulting in sustainable crop yields. Such a set of management tools can be practical, cheap and environmentally sound.

Phytochemicals discharged from plants and semiochemicals from insects are said be crucial to role in the behavioural events that determine the success or failure of managing insect pests. The communication of signals through specific chemicals between different organisms in an ecosystem is termed as chemical ecology (Greenblatt and Lewis, 1983). Volatile chemicals mediate in the web of interactions between organisms from different trophic levels, including phytophagy's, parasitoids and predators (Vet and Dicke, 1992). One such alternative gaining attention in research community is identification and use of pheromones for the management of *Conogethes* sp.

Sex pheromones to manage insect pests are being evaluated for the past several years. For select insects, application methods have already been established and are being used on commercial scale. Nevertheless, newer techniques are being developed constantly that are easier to apply and less costly and more effective than pesticides. Most female lepidopterous insects release the sex pheromones to attract males of the same species. Males find the females following the odor of the sex pheromone and then they mate. When the field is covered with sex pheromone, the communication for mating is confused. The mode of action of the pheromone is such as to affect the mating of shoot and fruit borers resulting in reduction of the population.

Sex pheromone composites of *C. punctiferalis* have been analyzed, synthetized and made into lure to attract male moths and disrupt mating in fields (Konno et al. 1982; Liu *et al.* 1994; Xiao *et al.* 2012; Du *et al.* 2014b). Among which, (*E*)-10-hexadecenal (E-16:Ald) was considered as principal component of pheromones, where as (*Z*)-10-hexadecenal (Z-16:Ald) as secondary component, and the field trapping effect was best when the ratio of these two components was 9:1 at 300.0 ug/lure (Konno *et al.* 1982). A synthetic pheromone lure is now available for trapping for surveys of the *Conogethes* moth populations. The data on moth catches by pheromone traps within fields is useful in assessing subsequent larval population trends. This is expected to permit a reduction in the number of insecticide spray applications without yield loss and marketability. Keeping this in view, the present study on **"Standardization of mass rearing technique and field evaluation of pheromone of shoot and capsule borer, *Conogethes* spp (Lepidoptera: Crambidae) on selected host plants"** were undertaken with the following objectives.

1. To study the seasonal incidence of *Conogethes* spp on select host plants.
2. To device a technique for mass rearing *Conogethes* spp populations on Castor and Cardamom.
3. Field evaluation of identified pheromone components of *Conogethes punctiferalis* population on Castor and Cardamom.
4. To standardize the sex pheromone trapping plan under field conditions.

II REVIEW OF LITERATURE

The published literature on Standardization of mass rearing technique and field evaluation response of moths to semiochemicals, longevity of pheromones, trapping techniques, trap density for maximum moth catches, seasonal patterns of pheromone trap catches, and mass trapping studies are reviewed in this chapter.

2.1 Geographical distribution

Conogethes Meyrick, 1884 is a genus of Spilomelinae in the family Crambidae and currently comprises 14 species (Table 1) (Shaffer *et al.*,1996; Inoue and Yamanaka, 2006) distributed in southern and eastern Asia, Australia, Indonesia, and New Guinea (USDA, 1957; Walker, 2007). Honda *et al.* (1979) stated that *Conogethes punctiferalis* is an important pest of chestnut and peach in Japan. It has been reported on papaya in Italy (IBPGR, 1988). Evangelista (1995) reported *C. punctiferalis* as a major pest of durian fruit in Philippines, with 6.66 to 31.82 per cent infestation. This species is also present in Hawaii (Nishida, 2002). *C. punctiferalis* is a pest of quarantine importance for apple in Mexico (Anonymous, 2005). *Conogethes* has also been observed outside its natural range, with findings in Hawaii (Munroe, 1989) and Great Britain (Truscott, 2007). It is also now reported to be a new and introduced pest in Britain and Europe (Stanley *et al.,* 2009).

The distribution of shoot and fruit borer extends from Asia to Australia (CABI, 2011). In Asia, it is found in China (Zhang, 1994; AQSIQ, 2007); India, Indonesia, Japan, Korea, Malaysia, Taiwan, Thailand, Vietnam, Brunei Darussalam, Cambodia, Myanmar, Philippines and Sri Lanka (Gour and Sriramulu, 1992; Hang *et al.*, 2000; Kang *et al.*, 2002; Chakravarthy 2015; Chakravarthy *et al.*,2015a; Singh and Kaur, 2015a; Singh and Kaur, 2016). Considering suitable area for the pest, most parts of North America, South East Asian countries, Australia, Africa and European countries are reported climatically suitable for this pest, though the pest is currently problematic in Asia and Australia. In Australia, New Zealand and European Union, it is a pest of quarantine importance. Therefore, invasiveness of this borer in these regions is critically important (Chakravarthy, 2015). From Oceania, the borer has been reported from Australia and Papua New Guinea (Waterhouse, 1993; Zhang, 1994; Púcat, 1995; EPPO, 2013; Chakravarthy, 2015; Molet,

2015). *C. punctiferalis* has been mentioned as a national threat in USA for grapes (Mellinda and Breiter, 2007) and is considered as a potential hazard in New Zealand (Reed 2009).

Economic importance of *Conogethes* spp

The complex structure of male genitalia and a broad larval host range rendered *Conogethes* as a taxonomically difficult taxon. There are two different types of *C. punctiferalis i.e.,* the fruit-feeding type on angiosperms and the Pinaceae-feeding type on Pinaceae gymnosperms (Koizumi, 1960). Inoue and Yamanaka (2006) re-described *C. punctiferalis* along with two new species (*C. parvipunctalis* Inoue and Yamanaka, 2006, fruit-feeding type group and *C. pinicolalis* Inoue and Yamanaka, 2006, feeding on Pinaceae) from eastern Palaearctic and Oriental regions. Wang *et al.* (2014) confirmed that *C. punctiferalis* and *C. pinicolalis* are two different species by reconstructing phylogenetic tree based upon sequence data from the combined gene markers COI, COII and Cytb of mitochondrial cytochrome. The type locality of *C. punctiferalis* is India. So many closely allied species are present. However, taxonomic revision of them has been neglected for a long time. *C. punctiferalis* is in focus because of the expanding host range, geographical occupancy, and complexity involved in species identifications. As the pest is an internal tissue borer, it is difficult to manage in fruit orchards and plantations. This insect group is undergoing speciation, genomic changes, or evolving into new taxon.

The accurate identification of insect species is one of the important aspects in entomological science. In most groups, traditional taxonomic research is based on morphological characters. It is difficult to identify cryptic and polymorphic species through conventional taxonomy. However, there are difficulties for want of experts. For this purpose, molecular methods have been found valuable in discriminating cryptic species of insects (Jackson and Resh, 1998; Pilgrim *et al.,* 2002).

Cryptic species are defined as two or more distinct species classified as a single nominal species because they are morphologically indistinguishable (Bickford *et al.,* 2007). One of the mechanisms thought to promote speciation in phytophagous insects is shifts to new hosts that lead to the establishment of new species *via* an intermediate step of

host-race formation and the occurrence of insect host races exhibit recently evolved genetic differentiation with respect to host-plant use (Dres and Mallet, 2002).

2.2 Host range

Conogethes spp. is a large taxon infesting more than 120 wild and cultivated host plants across the world. Ikemiya *et al.* (2008) reported grape fruits as host of this borer from Osaka, Japan. *C. punctiferalis* has been recorded as a pest of durian in Philippines, with 21-30 per cent infestation (Anonymous, 2008). It has been included in the list of pests regulated by Canadian Food Inspection Agency, Canada under *Plant Protection Act* (CFIA, 2016). The simulation model predicted southern, eastern, central and north eastern parts of India climatically suitable for the successful establishment of the pest (Sridhar *et al.,* 2015).

C. punctiferalis has been recorded as a pest of durian in Vietnam (Loc *et al.,* 2004). Cai *et al.,* (2005) reported it as a leading pest of loquat in China. While much of the species' distribution is in the subtropics, *C. punctiferalis* has also been recorded from Hokkaido prefecture, north Japan (Inoue and Yamanaka, 2006), and China (CABI, 2007 and CABI, 2011).

In India, guava, mango, peach, pomegranate, orange, mulberry and jackfruit are damaged while in other countries, *C. punctiferalis* was destructive pest on banana, apple, papaya, orange, peach, guava, pomegranate, plum, citrus, pear and loquat (Anonymous 1913a and b; David *et al.,* 1964; Konno *et al.,* 1981). Serious damage of this pest was recorded on guava in winter and rainy seasons (Ansari 1945; Butani 1979; Tandon 1988; Sandhu *et al.,* 1979). It is a serious pest on guava and castor in Punjab (Hans Raj 1979). Pruthi and Batra (1960) reported this borer as a sporadic pest on guava. The crop failure due to the attack of this borer is often common. It is a major pest of castor and cardamom and minor pest of pomegranate, jackfruit and tamarind (Atwal and Dhaliwal 1977). Rambutan is the host to *C. punctiferalis* in India (Osman and Chettana chitara 1987). Hussain *et al.* (1987) surveyed mango orchards in Bangladesh and reported *C. punctferalis* as a major pest. Singh and Kumar (1992) reported *Conogethes festivalis* (Swinhoe) infesting 11.36-33.33 % litchi fruits in 1st fortnight of June in 1988-90 in Bihar, India.

Larvae of the new pest made holes at the stalk-end of the fruit, bored through the pulp and into the seeds, where they feed on the endocarp and cotyledons. Affected fruits fall prematurely. The insect was described as being of restricted and local occurrence. He (1997) observed shoots, flower clusters, young leaves and fruits of *Fortunella* trees (Citrus) attacked by *C. punctiferalis* larvae throughout the year in Renshan, Sichuan and China. The most critical stage was when fruits began to turn orange. Ram *et al.* (1997) recorded *C. punctiferalis* infesting grapes for the first time in Karnataka. Fifty per cent reduction in yield was recorded on grapes due to this pest. At Ludhiana, Punjab, 9 to 14.6 % guava fruits were infested from last week of July to first week of October (Anonymous, 2000). Huang *et al.* (2000) reported longan, *Dimocarpus longan* as a host of *C. punctiferalis* in China.

Singh *et al.* (2002) observed boring into unripe mango fruits near stalk end in Sambhalhera village of Muzaffarnagar, Uttar Pradesh, India. It is reported to attack mango fruits during April-June in Tirupati, Andhra Pradesh (Kannan and Rao, 2007). Gundappa *et al.* (2015) reported that castor capsule borer has recently become a serious problem in mango growing tracts of Uttar Pradesh.

The pest has also been reported on apricot, citrus, ginger, guava, jackfruit, mango, mulberry, peach, pear, plum, tamarind and turmeric (Butani, 1979; Chakravarthy 2015; Singh and Kaur, 2015a; Singh and Kaur, 2015b; Singh and Kaur, 2016; Singh *et al.*, 2016). But as stated earlier, on zingiber plants, the borer species is different. *C. punctiferalis* is also an emerging pest of cocoa in India (Alagar, 2013), feeding on rind and pods causing premature drying and shedding of flowers and fruits. Chakravarthy (2015) reported that larvae of this crambid moth are typically polyphagous attacking more than 120 wild and cultivated plants. *Punica granatum* also served as host plant for this pest (Konno and Shishido, 1996; Peter, 1996; Chakravarthy *et al.*,1997; Park *et al.*,1998; Ganeshaaa *et al.*, 2013 and Kumar *et al.*, 2017). During May-June 2015, about 10 per cent borer infestation was recorded on litchi fruits in Hoshiarpur and Gurdaspur (Singh and Kaur, 2015b). Recently, the borer was observed infesting grapes during June 2016 in vineyards at Ludhiana, Punjab, for the first time.

In China, this species has caused serious damage and yield loss to peach, chestnut, sunflower and sorghum (Wang, 1991 and Wu *et al.,* 1999). Ma and Bai (2004) reported *C. punctiferalis* as a major pest of pomegranate fruits in China. Durian, *Durio zibethinus* in Thailand, fruits and maize crop in China (CPCI, 2005), more than 20 fruit crops including *Dimocarpus longan, Averrhoa carambola, Litchi chinensis* in Korea and *Helianthus annuus, Macadamia ternifolia* in New Zealand (CPCI, 2005).

The borer has been reported from Australia on banana, apple, papaya, orange, cotton, maize and sorghum; from China on pear; from Pakistan on loquat; from Java on teak and cocoa; and from Malaya on rambutan, *Nephelium lappaceum* L., as reviewed by workers (Anonymous 1913a & b; David *et al.,* 1964; Mishra and Teotia, 1965; Chay-Prove *et al.,* 2000). It is also reported on peach, plum, pomegranate and guava from Burma (Gosh 1940); pear (Kondo and Miyahara 1930) and peach from China (Young and Shaw, 1962); on mango, guava, mulberry, pomegranate, peach and pear (Fletcher 1921); loquat (Hussain 1924); orange (Pruthi and Mani 1945); jackfruit, avocado and pear (Anonymous 1952), and guava (Ansari 1945) from India. *C. punctiferalis* has also been recorded on peach as major pest (Konno *et al.,* 1980; Konno *et al.,* 1981; Kadoi and Kaneda 1990; Abe and Sanari, 1992; Kimura and Honda, 1999) in Japan.

Biosystematic studies of Japanese *Conogethes* spp. with special reference to host plant preference (Honda, 2013a) revealed that the two *Conogethes* species- *C. punctiferalis* (CPU) and *C. pinicolalis* (CPI) larvae showed host preference as CPU larvae were polyphagous but development delayed on CPI hosts while CPI larvae feed typically on conifer needles. Male moths of both species were cross attracted to calling females and to pheromone gland extracts because female sex pheromone systems of both are similar. Final conspecific sexual recognition in each species is accomplished by a male pheromone identified from hair pencil organs of CPU but no volatile pheromones from male CPI. Reports of *C. punctiferalis* on *Pinus* (pine), *Larix* (larch), *Cedrus* (cedar), *Abies* (fir) and other Pinaceae is likely to be *C. pinicolalis*, a species that was first described in 2006 (Inoue and Yamanaka, 2006).

Table 1. Currently recognised *Conogethes* species and their synonyms (from Nuss *et al.*, 2003–2017) and larval food plants

Species of *Conogethes*	Type locality	Known larval food plants
C. spirosticha Meyrick, 1934	Indonesia, Java, Telawa	Unknown
C. punctiferalis (Guenée, 1854)	India	On a large number of angiosperms, see e.g. Inoue and Yamanaka (2006)
= *Asturaguttatalis* Walker, 1866	Indonesia, West Papua, Misool; North Maluku, Bacan Islands; Aru; Seram	
= *Botysnicippealis* Walker, 1859	Indonesia, Maluku, Seram	
= *Conogethes punctiferalis* var. *jocata* T. P. Lucas,1892	Australia, Hamilton Scrub near Brisbane	
= *Deiopeiadetracta* Walker, 1859	Singapore	
C. semifascialis (Walker, 1866)	Australia, Moreton Bay	Unknown
= *C. jubata* T. P. Lucas, 1900	Australia, Queensland, Brisbane	Unknown
= *Conogethes punctiferalis* var. *nigralis* Warren, 1896	India, Meghalaya, Khasi Hills	
C. tharsalea (Meyrick, 1887)	Australia	Unknown
C. pluto (Butler, 1887)	Solomon Islands, Shortland Island	*Alpinia* (Zingiberaceae) (El-Sayed *et al.*,2012)
C. haemactalis Snellen, 1890	India, Sikkim	Unknown
= *C. nubifera* T. P. Lucas, 1892	Australia, Brisbane, Birpengarry	
C. diminutiva Warren, 1896	India, Meghalaya, Khasi Hills	*Ipomoea* (Convolvulaceae) (Robinson *et al.*,2010)
C. mimastis Meyrick, 1897	Indonesia, Sangir Island	Unknown
C. parvipunctalis Inoue & Yamanaka, 2006	Japan, Ryuku, Amami-ôshima, Hatsuno	Unknown
C. pinicolalis Inoue & Yamanaka, 2006	Japan, Honshu, Saitama Pref., Iruma City, Bushi	*Pinus*, *Picea*, *Tsuga*, *Larix*, *Abies*, *Cedrus*(Pinaceae) (Inoue and Yamanaka 2006)
Conogethes sahyadreinsis	Mudigere, Chikmagalur, Karnataka, India	*Elettaria* (Zingiberaceae) (Shashank *et al.*, 2018)

Nowadays, DNA bar coding is a major tool for species identification and molecular taxonomy provides additional support for species identification through traditional taxonomy. Seventeen species from six countries, namely, Australia, Papua New Guinea, Cambodia, China, Indonesia and Nepal were bar coded for genus Conogethes and deposited in BOLD to date (Shashank *et al.,* 2015).

Studies on host plants and severity on different fruit crops, surveys were conducted during 2013-14 and 2014-15 in different agro-climatic zones of Punjab i.e. south western arid zone, central plain zone and sub-mountainous zone along with fixed plot surveys revealed that *C. punctiferalis* was an active pest on eight fruit crops i.e. ber, loquat, peach, mango, pomegranate, plum, pear and guava in Punjab (Singh and Kaur, 2014; Singh and Kaur, 2015a; Singh and Kaur, 2015b; Singh and Kaur, 2016; Singh *et al.,* 2016).

An attempt was made to study the influence of climate change on distribution of *C. punctiferalis*, the CLIMEX software was used to predict climatically suitable locations for *C. punctiferalis* (base year 1962-1991) and future climate change situation that is 10^0C increasing global temperature. A north world expansion of suitability was predicted in North America, China, European countries and south world expansion was predicted in South America mainly attributed to a decrease in cold stress (Sridhar *et al.,* 2015).

2.3 Seasonal Incidence

Shoot and fruit borer, *C. sahyadreinsis* (now recognized as a different species) occurred throughout the year on Cardamom in Western Ghats in South India. Two peaks in the borer population were noticed in a year, i.e. one during April - May and the other during November – December (Thyagaraj, 2003). The population coincided with the period of less or no rainfall, i.e. during pre and post-monsoon periods (Ballard, 1927; Ono, 1937; Thyagaraj, 2003).

The damage of *C. punctiferalis* on cocoa was observed from December 2010 to May 2013. The infestation of *C. punctiferalis* started immediately after monsoon and the peak incidence was observed during March to May (Alagar, 2013). Temperature and rainfall influences greatly the growth and development of the borer life stages (Rao, 1992).

The overwintering of the needle feeding type / Pinaceae feeding type of the yellow peach moth, *C. punctiferalis* were studied in China and Korea under laboratory and field conditions. They observed that third or fourth instar larvae rolled the needles in twigs into a bag with silk, in which they overwintered (Kang *et al.,* 2004; Kuang *et al.*, 2009).

Severe damage was observed on fruits of peach, pear, plum in Punjab Agricultural University (PAU), Ludhiana during May-June 2015. The larvae bored into the fruits and fed on the pulp. Peak activity was recorded during April-May (Singh *et al.,* 2016; Singh and Kaur, 2016). The population of borer, *C. sahyadreinsis* was recorded in the field throughout the year on cardamom but is reported to be higher during January–February, May and September–October at Idukki (Kerala) (Varadarasan *et al.,* 1989) and during January, March, June, August and October at Thadiyankudisai (Varadarasan *et al.,* 1991). At Mudigere (Karnataka), it was reported to peak during September-October on the cardamom tillers (Krishnamurthy *et al.,* 1989). On ginger, the borer is known to occur throughout the crop period in Kerala during July to December. In Kottayam and Idukki districts, the damage was higher during August, September, and October (Nybe, 2001).

On turmeric, *C. sahyadreinsis* occurred throughout the crop period in Kerala during July to December. The pattern of distribution of *Conogethes* species in a turmeric field at Peruvannamuzhi was random during July to September and became more aggregated during October to December. The symptoms of fresh pest infestation were higher during October to December (Devasahayam *et al.,* 2010a).

2.4 Damage and Crop loss

The amount and type of damage caused by this species and most reports are limited to a specific or few crops (Korycinska, 2012). The borer has been reported as a destructive pest of temperate fruits in China and cotton in Australia. *C. punctiferalis* has been documented as a serious pest of castor bean and fruits in tropical, sub-tropical and temperate countries (USDA, 1957). In India, Devasahayam and Koya (2005) reported that this species is the most serious pest of ginger, particularly in south India. Crop yield can be significantly affected when more than 45% of shoots in a clump are damaged (Devasahayam *et al.*, 2010). Ansari (1945) reported that larvae fed on guava fruits and

passed larval and pupal stages inside the fruit. Infested fruits dry up and drop before maturity. Sengupta and Behura (1957) observed larvae boring into young mango fruits but confined to pulp only and did not attack stone. Presence of granular faecal matter, entangled in the webbing, at the entrance hole was recorded with typical symptoms for identification of damage caused by this borer (Singh and Kaur, 2016). In south India, small cardamom capsule yield loss was recorded between 6.8 and 9.2% while castor capsule damage was between 11 and 27% (Shashank *et al.,* 2015). The damage on castor was 16% to 72% (Bilapate and Talati, 1977). In Gujarat, 63% weight loss of damaged seeds of castor and more than 20% yield loss in cardamom were observed due to *C. punctiferalis* and *C. sahyadriensis*, respectively (Kapadia, 1996). The yield of the crop is significantly affected when more than 45% of the shoots in a clump are damaged by the pest in ginger (Koya *et al.,* 1986).

Shoot and capsule borer infests shoot, stem, panicles, flowers and capsules of cardamom and caused yield loss of 70 to 80 per cent (Varadarasan, 2001). However, in ginger and turmeric, the shoot borer caused yield loss up to 50 per cent (Senthil *et al.,* 2015). In Guatemala and other countries, the borer damage on small cardamom varied widely (5-30%). In small cardamom, the yield loss was estimated to be more than 20 % every year (Kapadia, 1996; Thyagaraj, 2003). However, the crop loss due to this pest was worked out in small cardamom and economic threshold level was fixed at 10 % (Krishnamurthy *et al.,* 1989; Ram *et al.,* 1997). Suganthy (2011) estimated capsule yield loss in castor in Tamil Nadu to be 10.80 –26.70 % and estimated 42.30 % crop loss in India (Kapadia, 1996) and 50% yield reduction in grapes (Ram *et al.*,1997).

The larvae of *C. punctiferalis* entered a quiescent stage during December, January and first half of February and over wintering larvae resumed their activity when they are exposed to a temperature of 25°C (Srivastava and Awasthi, 1961). The capsule borer was generally active in main crop season with occurrence of all stages from March to April (Mishra and Teotia, 1965). Castor shoot and capsule borer was found all through the year and was usually severe during November to March in the main crop season (Rai, 1976). The maximum and minimum temperature influenced positively with significant effect on per cent infestation of capsule by shoot and capsule borer (Goel and Kumar, 1990).

The borer population was relatively higher from August to September and March to April coinciding with the peak harvest of durian in the Philippines (Evangelista, 1995). Asokan and Kempuchetty (2000) reported that incidence of capsule borer started from November-December with 1 to 3 per cent capsule damage in the rainfed castor as intercrop. The peak period of damage was more during January-February and extended up to March – April. However, castor as pure irrigated crop (hybrid) was attacked by capsule borer even during October and 30-50 per cent damage was noticed in November- December. Gupta and Arora (2001) revealed that severe infestation of *C. punctiferalis* on guava was first noticed during the second fortnight of October with 2.5 per cent fruit infestation that subsequently reached a maximum of 23.0 per cent in the fourth week of November and extended up to second week of March.

Xi *et al.* (1996) reported that fruits of Chinese chestnut (*Castanea mollissima*) suffered 25-80 per cent loss due to *C. punctiferalis*. A total of 120 tonnes of *C. mollissima* was damaged and one million Yuan RMB of revenue lost every year due to *C. punctiferalis*, one of the main insect pests in China. Therefore, effective control was carried out on the basis of occurrence rhythm (Xu *et al.,* 2001). In Malaysia, Mohamed (1998) recorded an infestation of about 4% on durian.

Thirupati Reddy (2002) reported that the initial incidence of the infestation of capsule by *C. punctiferalis* started in first week of February with 14.16 per cent and the maximum damage of capsules was observed during last week of March with 32.94 per cent of capsule infestation. The relationship between the weather parameters and capsule infestation was significant and positive between percent infestation of capsule and maximum temperature/minimum temperature, while negative and significant relation was found between infestation and humidity.

Kaul and Kesar (2003) studied seasonal incidence of the borer at two locations viz., Udheywalla (irrigated) and Raya (rainfed), of Jammu, India on guava cv. Lucknow-49. The highest incidence (20%) was noted in the 32nd standard week at Udheywalla, while peak incidence (9%) was recorded in 33rd standard week at Raya. A comparison of the infestation levels at Udheywalla and Raya revealed that fruit borer infestation was higher

in irrigated compared to the rainfed area. On guava, during mid-August to end-October, 10-15 per cent fruit infestation was recorded in Ludhiana, Patiala and Moga, Punjab (Singh and Kaur, 2015a). On mango, borer infestation was recorded in Ludhiana, Hoshiarpur and Patiala (Punjab) during May-June with 5-10 per cent fruit infestation (Singh *et al.,* 2016).

Madhuri (2005) reported that the activity of shoot and capsule borer was initiated during the last week of January and capsule infestation reached peak level by first week of March. The correlation between capsule infestation and mean maximum temperature was significant and positive while relative humidities had significant negative correlation and rainfall had non-significant negative and non-significant correlation.

Gundappa *et al.* (2015) reported that on egg hatching, the caterpillars of the borer bore into mango fruits, bud or shoot and feed within, on pulp and seeds or soft tissues. The fruit borer affects both mesocarp as well as seed but preferably on seeds in mango. The pest render fruits unfit for human consumption. The larva feeds on the rinds of fruits, later bore inside and feeds on internal contents. The granular fecal pellets are seen outside the fruits. When fruits are in close proximity, it forms favourable niche for the larva to bore into fruits. Fruits damaged by this pest are exposed to secondary infection by pathogens leading to black corky appearance on the epicarp. Singh and Kaur (2016) recorded *C. punctiferalis* larvae feeding tunnels on mango inflorescence in Hoshiarpur, Punjab. Larvae were observed to bore and tunnel the fruits by joining two fruits together. Black frass was also seen near entrance and attacked fruits rot and drop-off. One larva per fruit was observed causing about 10 per cent damage to fruits (Singh and Kaur, 2014).

C. sahyadreinsis is the most serious pest on ginger and turmeric and this species cause damage upto 35% on ginger (Thakur *et al.*, 2012) in Meghalaya. In Sikkim it causes 15-35% damage (Yadav *et al*., 2014). It causes severe production loss in ginger in Nagaland (Lalnuntlunga, 2005). The borer is one of the most serious pests in North Eastern India (Mhonchumo *et al.*, 2010). The economic threshold level (ETL) of this species worked out on ginger in NER. Management methods should be adopted at stage when there is one egg mass per square meter (Darlong *et al.*, 2006).

Gravid females of *C. punctiferalis* reared on castor emerged four hours (17.78 %) after lights-off (ALO), those reared on cardamom emerged an hour (23.46 %) ALO. The calling frequency was more pronounced in female *C. punctiferalis* reared on castor compared to that on cardamom. *C. punctiferalis* (now recognized as a different species) moths reared on cardamom showed peak mating activity between 4 to 6 hours ALO, while 6 to 9 hours in females reared on castor. Failure of hybridization between *C. punctiferalis* reared on castor and cardamom suggest that the two *C. punctiferalis* populations segregated into two species (Shashank *at al*., 2014).

Presently, *C. punctiferalis* is emerging as a major pest on cocoa in India. *C. punctiferalis* larvae bore in to the pods, feed on the internal contents of the pods, attract secondary infection and emerge as adult (Alagar *et al.,* 2013). Even though the recorded damage potential was less (2.07%), the main concern is in the similarity of feeding behaviour with that of cocoa pod borer *Conophomorpha gramerella* (Snellen) (Gracillariidae: Lepidoptera), serious pest in Malaysia, Indonesia, Java, East New Britain, Papua New Guinea (Ooi *et al.*, 1987; Azhar, 1995; Azhar *et al.* 2001) causing 20-50 per cent yield loss (Mumford, 1984). Pomegranate fruits were found infested with yellow peach moth larvae during May and July-August with 15-20 per cent infestation in Ludhiana, Jalandhar and Fazilka, Punjab (Singh *et al.,* 2016).

2.5 Bio-ecology

2.5.1 Egg

Biological study of *C. punctiferalis* on castor under laboratory conditions revealed that gravid females laid pale yellowish, oval, flat eggs singly on capsules, inflorescence (raceme). The incubation period was 2.51±0.85 days (Kumar *et al.,* 2017). The results on biology of C. *punctiferalis* under lab conditions on castor revealed that eggs were oval, translucent, with incubation period of 3.7±0.50 days; fecundity was 52±1.65 eggs per female and 85.61±3.65 per cent egg viability (Ambanna, 2014). Eggs of *C. punctiferalis* are round; light yellow, 0.63 x 0.41 mm. After incubation of 6 to 7 days, eggs turned dark brown with a dark head (Bilapate and Talati, 1978; Jarvis, 1914 and Thyagaraj, 2003).

Biology of *Conogethes* sp. on cardamom, turmeric and ginger in Mudigere, Karnataka, South India by Kasareddy (2017) revealed that eggs were oval, translucent, with incubation period of 4.00 ± 0.20, 4.00 ± 0.36 and 4.00 ± 0.05 days, in cardamom, turmeric and ginger, respectively.

The most favourable conditions for oviposition in the laboratory were 22-31ºC and 50-90 per cent RH (Jacob, 1981). *C. punctiferalis* moths laid eggs singly or in groups 1-6 on castor inflorescences between the warts or just below the style on the ovary of the flowers and on the developing capsule up to the stage it is half mature. The egg stage lasted from two to four days at 30ºC to 11 days at 20ºC in the laboratory (Patel and Gangrade, 1971; Stanley *et al.,* 2009). Observations on ovipositional preference on different substrates and plant parts revealed that the gravid female moths laid maximum numbers of eggs on the cotton plug (41.97%) and castor twigs (41-48 eggs/ female). Observations on the oviposition pattern of female moths revealed that the highest number of eggs (82) were found on cotton plug in a total life span of female moth, the highest fecundity was found between 3 to 5 days, that is 18, 25, and 20 on third, fourth and fifth days, respectively (Kumar *et al.*, 2016).

According to Bilapate and Talati (1978) the average length and width of eggs of *C. punctiferalis* were 0.59 and 0.39 mm, respectively. The incubation period of the eggs averaged 4.13 ± 0.80 days on castor. Devasahayam *et al.* (2010) reported that adult moths laid eggs on the tender unopened leaf of ginger (*Zingiber officinale* Rosc.). Egg of *C. punctiferalis* is round, light yellow measuring 0.63 x 0.41 mm in size. After incubation of 6 to 7 days, egg turned to dark brown with a dark head under laboratory conditions (Bilapate and Talati, 1978; Jarvis, 1914; Thyagaraj, 2003). The host phenology influenced the size, growth and development of eggs of this pest when fed on different host plants (Bilapate and Talati, 1978; Jacob, 1981; Twine, 1971). There was a significant difference in per cent hatching from 65.0 ± 0.76 to 90.5 ± 1.38 and incubation period from 4.19 ± 0.80 to 9.35 ± 1.05 days under varied temperature and relative humidity (Thyagaraj, 2003; Wang and Cai, 1997). Temperature and relative humidity play an important role in the biology of the egg (Kondo and Miyahara, 1930; Rajan, 1965; Mukerji and Gage, 1978).

The egg character and relationship with temperature and relative humidity have been extensively studied in laboratory (Thyagaraj, 2003).

2.5.2 Larva

As soon as the egg hatched, young (neonate) larva bored into the pseudo stem or capsules (depending on the availability). On the pseudostem, larvae bored at the base of leaf axis and entered inside the shoot (Jacob, 1981). The excreta plugged at the entry hole on the shoot indicated larval boring (Thyagaraj, 2003). Larva fed on the shoot was light greenish while larva fed on the capsules was light yellow (Bilapate, 1977; Thyagaraj, 2003). Larva remains inside the pseudostem till pupation. Therefore, it is difficult to study the larval instars directly. Dyar's law was applied to record number of larval instars and there were five larval instars (Dyar, 1890; Thyagaraj, 2003). Observations revealed that there was no major difference among the instars excepting for head and body size. All larval instars were very active and when disturbed they tried to fall down with a fine silken thread (Bilapate and Talati, 1978; Kondo and Miyahara, 1930; Kodoi and Kaneda, 1990; Thyagaraj, 2003; Twine, 1971; Young and Shaw, 1962).

The growth and development of different stages of larva varied with varying temperature and relative humidity conditions. Each larval instar lasted for 3-4 days and the total larval period extended up to 12-14 days (Bilapate, 1977; Jacob, 1981; Kondo and Miyahara, 1930; Twine, 1971; Wang and Cai, 1997; Xi *et al.*, 1996). The larval period varied from 12.55 to 19.59 days and the per cent survival, from 49.6 to 92.8 at 28 degree celsius and 80 ± 5.0 per cent relative humidity were most favorable for the development of larva (Thyagaraj, 2003; Koya *et al.,* 1986). First, second, third, fourth and fifth instar larvae occupied durations of 4.1±0.50, 4.08±0.90, 4.22±0.90, 4.0±1.0 and 3.9±1.1 days, respectively (Ambanna, 2014). The average duration of fifth instar larva reared on cardamom, turmeric and ginger was 7.50 ± 0.82, 6.90 ± 0.69 and 8.75 ± 0.81 days, respectively (Kasareddy, 2017).

For understanding the larval morphological characters and chaetotaxy in this section review on larvae of other Lepidoptera pests along with *Conogethes* are also included. Forbes (1910) explained the external characteristic of the groups of caterpillars

mainly dealing with the parts, sclerites and setae of the head, mouth parts and the arrangement of the proleg hooks. These studies provided a key for identification of 24 families of the sub order Frenatae, which is mainly based on setae, hooks of prolegs, shape of caterpillars and the mouth parts.

Fracker (1915) described the caterpillars with an investigation of the homology and monotype of the setae. The studies described the new species and new instars in a manner which will make like-specimens recognizable in the future without repeating studies on biology. He also discussed the arrangement of primary and sub-primary setae and classified these Lepidoptera larvae based on head sclerites, head setae, armature, shape of spiracles, number and arrangement of crochets on the abdominal prologs, the nature and shape of the spiracles and the position of the trapezoidal tubercles on the abdomen.

2.5.3 Pupa and Sex ratio

Pupation of *Conogethes* took place in cocoons inside or between the capsules and the pupal stage lasted for 7-10 days (Patel and Gangrade, 1971; Bilapate and Talati, 1978; Gour and Sriramulu, 1992). The duration of insect development varied from 27 days at 30ºC to 48-51 days at 20ºC. Pupal period took over eight weeks and more in winter on sorghum in Queensland, Australia (Sloan, 1945). Prepupal, and pupal periods of the borer were 2.75±0.80 and 9.50±0.70 days, respectively (Kumar *et al.*, 2017).

According to Wu (1995) 86.5 per cent larvae of *C. punctiferalis* pupated in leaf axils and on the tops of the ears of maize and 13.5 percent pupated in stalks. Thyagaraj *et al.* (2001) reported that the female pupae were generally bigger in size. The male pupae were shorter, slightly narrower and the genital opening was located in the posterior region of the ninth abdominal segment and flanked by a pair of pads. Significant differences were also noticed between the sexes in terms of length and diameter.

There is a clear difference in the size, shape and weight of the male and female pupa. Female pupae were bigger (17.81 x 6.29 mm with 0.127 gm in weight). Male pupa measured 14.30 x 4.26 mm with 0.108 gm weight (Thyagaraj, 2003). There was no significant difference in the pupal period under different temperature regimes (20.0 to 38.0

± 1.00oc (Bilapate, 1977; Jacob, 1981; Mihra and Teotia, 1965; Wang and Cai, 1997). Sex determination at the pupal stage of the insect certainly helps in the development process of management like sex attractants, etc. There is sexual dimorphism in the *Conogethes* pupa (Peterson, 1967; Sithanantham and Subramaniam, 1975).

It is important to know the sex ratio in the field for pest management. Male-female ratio will be much useful in using sex attractants (pheromones). The mean sex ratio worked out to be 1:1.095 (1:1.2) male to female in *C. punctiferalis* (Bilapate and Talati, 1977; Sithanantham and Subramaniam, 1975; Thyagaraj, 2003). Adult longevity studies clearly indicated that there is no significant difference between male and female moths but laboratory studies with artificial diet showed difference in longevity between male and female, i.e. female moths survived 2-3 days more than male (Shanuowr *et al.,* 1993; Sithanantham and Subramaniam, 1975). Sex ratio was fixed to 1:1.3 (Pruthi, 1944; Young and Shaw, 1962).

2.5.4 Adult

Bilapate and Talati (1978) revealed that the males survived for 14.00 ± 3.80 days compared to 15.80 ± 2.50 days for females. The ratio of males to females of the progeny ranged between 1:1 and 1:2. The rate of occurrence of the banded adult form, *C. punctiferalis* varied between one and five per cent during different months. This may result from malnourishment as observed by Chakravarthy (1980s) across several rearing on different host plants. Kaneko (1978) observed a clear abdominal constriction in female *C. punctiferalis* that had already paired. This proved a reliable indication of pairing and greatly facilitated the separation of virgin and paired females in the course of mass-rearing. The constriction was apparent 45-60 minutes after pairing. Kumar *et al.* (2017) reported that the adult longevity of male and female was 7.50 – 9.00 and 8.00±0.70 days, respectively. Where as Ambanna (2014) reported that the longevity of male and female was 8.91±0.61 and 9.61±2.05 days, respectively.

2.5.5 Life cycle

Life cycle of an insect depends on the changed environmental factors, especially with temperature, relative humidity and altitude (Bilapate and Talati, 1978). Insect

population is primarily controlled by weather. Similarly, *Conogethes* showed a clear difference in life cycle. Life cycle of this pest was studied under laboratory as well as field conditions. Under laboratory conditions (28.0 ± 1.0^{o}c & 80.0 ± 5.0 % RH), the incubation period lasted for a mean of 5.3 ± 0.49 days. Larval period 17.62 ± 4.88 days, pupal period 8.81 ± 0.69 days and the mean male and female longevity was worked out to be 14.26 ± 3.29 and 15.29 ± 3.39 days, respectively. The total life cycle from egg to adult emergence required a mean of 31.75 ± 10.16 days (Pruthi, 1944; Young and Shaw, 1962). The average developmental period of this borer on castor was 32.3±1.10 days (Ambanna, 2014). The life cycle under laboratory conditions ranged from 25 to 33 days on cocoa (Alagar *et al.,* 2013).

Under field conditions (cardamom plantation), the incubation period lasted for 8.51 ± 0.65 days, larval period 25.49 ± 4.76 days, pupal period 9.55 ± 1.12 days and the total life cycle from egg to adult emergence was 43.63 ± 11.23 days. There was 8-10 days difference in the total number of days in a particular generation. However, there were differences in the life cycle between generation to generation due to changed environmental conditions (Pruthi, 1944; Young and Shaw, 1962). The total development period of male and female moths was maximum (42.45 ± 5.38 and 44.05 ± 5.24) when reared on turmeric compared to *C. sahyadriensis* reared on cardamom and ginger 37.80 ± 1.91, 39.25 ± 1.75 and 40.10 ± 1.37, 42.50 ± 3.50d, respectively (Kasareddy, 2017).

C punctiferalis completed lifecycle within a shorter period on castor, followed by cardamom, guava and ginger under laboratory conditions. The number of days taken by neonate larva to become adult was 27.76 on castor and 30.69 days on cardamom, while it was 32.05 on ginger (Stanley *et al.,* 2009). Shoot and capsule borer took about 30.37 – 35.30 days with on an average 30.65±3.70 days to complete life cycle from oviposition to adult emergence on castor (Kumar *et al.,* 2017).

2.6 Artificial diet

The literature pertaining to artificial diet on *C. punctiferalis* (Lepidoptera: Crambidae) on castor and other host is scanty. Hence, observation recorded on other hosts and other lepidopteran insects also has been reviewed and presented here under.

Artificially reared phytophagous insects such as Lepidoptera are suitable for studies on aspects like insect physiology, insecticidal action, growth and development, effect of entomopathogens, attractants, pheromones and host plant relationships. Artificial diets can be used to synchronize insect development with the food availability and can be used to optimize fitness of insects, sometimes more than their natural host (McMorran, 1965). The first insect to be reared from egg to adult on an artificial diet was *Calliphora vomitoria* Linnaeus (Bogdanow, 1908), which was axenically reared on a diet of meat extract, starch, peptone and mineral salts. Bottger (1942) was the first entomologist to rear a lepidopteran pest, *Ostinia nubilalis* (Hubn.) on artificial diet. Later, Vanderzant and Reiser (1956, 1956a) mass reared the notorious cotton pest, pink bollworm, *Pectinophora gossypiella* Saunders on a wheat germ-based diet. McMorran (1965) developed a suitable diet to mass rear the noctuid moths, particularly the pest species. Over the past nearly eight decades, entomologists have developed artificial diets for several insect species and the recipes of all these diets have been compiled (Singh, 1977). Of all the orders of insects, maximum number (258) of artificial diets have been prepared for Lepidoptera and for 12 species of crambid moths, the artificial diet has been attempted (Singh, 1977) (Table 2).

Honda *et al.* (1979) from Japan were the first to report meridic diet for *C. punctiferalis.* Utsumi *et al.* (1990) also proposed meridic diet for *C. punctiferalis* but both diets had lower yields of insects. However, these attempts provided useful baseline data for developing a well defined diet for the shoot and fruit borer, *C. punctiferalis*. From 1979 to date five teams of entomologists have attempted mass rearing of *Conogethes* on artificial diets (Table 3). The rearing of an insect in the laboratory requires: (i) establishment of insect colony, (ii) rearing facilities, (iii) research and development of rearing techniques, (iv) resources, (v) quality control and (vi) production (Taneja and Nwanze, 1990).

Table 2. Species of Crambid moths reared on artificial diets

Crambid Species	References
Conogethes punctiferalis	Honda *et al.* (1979); Utsumi *et al.* (1990); Chakravarthy *et al.* (1992); Li *et al.* (2014); Ambanna (2014) and Kumar *et al.* (2016)
Grapholita molesta (Busck)	Wang *et al.* (2011)
Chilo suppressalis Walker	Kamano (1965, 1971 and 1973); Kamano and Yushima (1969); Hormchong *et al.* (1972) and Ishii (1971)
Chilo agamemnon Bleszynski	Isa (1972)
Chilo auricilius (Dudgeon)	Varm and Avasthy (1973)
Chilo orichalcociliellus Strand	Delobel (1975)
Chilo zonellus Swinhoe	Chatterji *et al.,* (1968), Pant *et al.* (1960), Dang *et al.* (1970); Siddiqui and Chatterji (1972)
Crambus teterrellus (Zincken)	Ward and Pass (1969)
Crambus trisectus (Walker)	Dupink and Kamm (1970)
Diatraea grandiosella (Dyar)	Chippendale (1970); Keaster and Harrendorf (1965); Pan and Long (1961)
Diatraea saccharalis (Fab.)	Dinther *et al.* (1970); Hensley and Hammond (1968); Miskimen (1965); Wongsiri and Randolph (1962)
Scirpophaga novella (Fab.)	Wahid and Akhtar (1971)

Table 3. Mass rearing of *Conogethes* species

Species	References	Comments
C. punctiferalis	Honda *et al.* (1979)	Meridic diets fed colonies had a lower larval survival rate and a larger variation in development duration than colonies fed on natural host plant materials
C. punctiferalis	Utsumi *et al.* (1990)	Meridic diets fed colonies had a lower larval survival rate and a larger variation in development duration than colonies fed on natural host plant materials
Grapholita molesta (Busck)	Wang *et al.* (2011)	Diet for successfully rearing the Oriental fruit moth
C. punctiferalis	Li *et al.* (2014)	Larvae fed on fresh corn and chestnut performed better than those fed on apple, pear or plum
C. punctiferalis	Ambanna (2014)	Reared from egg to adult

2.6.1 Diet Composition

Insect diets are classified into 3 groups. First group is chemically defined (holidic) diet and used for studies of nutrition and metabolic pathways. Second group of diet contains one or more unrefined plants or animal substance such as liver powder or extract, yeast, wheat germ or other ingredients of a similar nature. Important characteristics of diets are that most of the nutrients are provided as pure or refined substances and used for laboratory rearing of insects. Third group of diet is composed of crude materials and are designed to imitate the natural food, or/ composed of high nutrient content. The efficiency and utilization of these diets can be improved with an increased understanding of the nutrition of the species. These diets are economical and are used for mass rearing insects (Singh, 1977).

The successful formulation of an artificial diet depends on a sound, basic understanding of nutrition, the chemical composition of the insect and its natural food, and knowledge of the habitat and feeding behavior of the species. Four principle requirements in formulating a diet are that it must be physically and /or chemically attractive so that it induces and stimulates the insect feed on an unfamiliar food; it must possess all the essential nutrients in balanced proportions needed for normal growth, development and reproduction and it must be free from microbial contamination (Singh, 1977).

Many species of lepidopterans, coleopterans and dipterans have been successfully reared under laboratory conditions (Gupta *et al.*, 2005). Like other animal taxa, crambid moths require proteins, lipids, minerals, carbohydrates, water, vitamins and fibers. For the protein source, entomologists have deployed milk proteins or casein or soy flour. This depends on the availability of the protein source. Lipids are supplied by wheat germ and the leaves. Corn oil may also be used as a source. Carbohydrate can be delivered to the insects using sugars as glucose/sucrose/fructose. Entomologists have been utilizing yeast or yeast powder as a source of vitamins (Morton, 1979). Commercial salts have been frequently used in diets as source of minerals. Usually Wesson salt or / and choline/ ascorbic acid has been used (Morton, 1979 and Gupta *et al.*, 2005).

The diets differed in the amounts of soybean meal, Corn meal and Chestnut meal, in the amounts of agar used. Only slight changes in constituents and composition of a diet can have profound influence on quality and quantity of insects produced. Further, the insects should be produced at reasonable costs, efficiently. Quality diets should result in higher survival rates, greater pupal and larval weights, shorter life cycles and greater fecundity rates (Du *et al.,* 2015).

Each constituent in the diet has a role in the growth and development of *C. punctiferalis*. For instance, larvae of *C. punctiferalis* reared on chestnuts developed faster and had a higher survival rate than larvae reared on peach, cypress or persimmon (Choi *et al.,* 2006; Honda *et al.,* 1979). This indicated that chestnut is an useful ingredient in the meridic diet for *C. punctiferalis*. Accordingly, Li *et al.* (2014) from China reported that *C. punctiferalis* larvae reared on fresh corn and chestnut performed better than those reared on temperate fruits like peach, plum, pear, apple, etc. Studies of Du *et al.* (2015) have indicated that diets having sorbic acid or formaldehyde as microbial inhibitors were unsuitable. Some workers like Du *et al.* (2015) derived the meridic diet of *C. punctiferalis* from a close genera like the Oriental fruit moth, *Grapholitha molesta* (Busck) (Lepidoptera: Tortricidae) (Wang *et al.,* 2011).

Significant ($p<0.05$) results for most of the rearing parameters were found among the four diets in the studies of Du *et al.* (2015). The life of *C. punctiferalis* varied from 42.4 to 63.3 days among the diets tested. The diet containing 30g chestnut meal, 70g corn meal and 70g soybean meal proved the best (Du *et al.,* 2015). Since the work on *Conogethes* mass rearing is limited, one can get ideas for research to improve mass rearing from other species of moths or closely related family pyralidae. Pyraloidea is super family in which *Conogethes* and other genera like *Chilo* and *Maruca* are included and are closely related. Of the species of *Chilo, Chilo suppresalis* Walker on rice and *Chilo partellus* Swinhoe on maize have received considerable attention for mass rearing. These species of moths were successfully reared in laboratory and then mass reared on artificial diet (Taneja and Nwanze, 1990). According to Chambers (1977) mass rearing should result in the production of tens of thousands to one million times the native productivity of the insect population.

The artificial diet for *C. partellus* included glucose, salt mixture, casein, yeast, choline chloride, cholesterol, cellulose, leaf factor, agar, water and methyl paraben (Pant *et al.,* 1960). Subsequently Chatterji *et al.* (1968) reared *C. partellus* on wheat germ based diet. Dang *et al.* (1970) for the first time introduced kabuli gram-based diet crambids used successfully by workers in India for rearing several species of lepidopterans including pyralids. At International Crop Research Institute for Semi-Arid Tropics (ICRISAT), Hyderabad, India mass culture of *C. partellus* is perfected and maintained throughout the year. Similarly, Sandeep singh (2016) in Punjab, mass reared *C. punctiferalis* on natural fruits of temperate fruits like peach, pear and tropical fruits like guava in Punjab using wooden wire-mesh cages ($0.3m^3$).

Ballal *et al.* (1995) successfully used an artificial diet across several seasons for rearing *Chilo partellus* at the National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru which was evaluated systematically up to five generations. The diet was compounded with chickpea flour (100g), yeast tablets (10g), maize leaf powder (10g), casein (30g), ascorbic acid (3g), sorbic acid (1g), salt mixture no.2 (1.5g), multi vitex capsules (2 Nos.), methyl parahydroxy benzoate (2g), streptomycin sulphate (0.25), agar-agar (10g) formalin (2ml) and distilled water (700ml). At the end three generations of rearing on this diet the larval survival was 75%, also, the weight of male pupa (0.055g), female pupa (0.188g) and mean fecundity per female (232.33) were recorded. The diet could be stored at $5^0 \pm 1^0$Ceven up to 10 days without effecting on the quality of the insects. The cost of rearing a hundred pupa on the above diet was Rs. 18.

The artificial diet perfected by Kobayshi *et al.* (2008) comprises carbohydrate, a protein and stable isotope. The protein originates from a microorganism that is subjected to a defatting treatment and a step with hydrothermal solution. The artificial diet also includes a vitamin and a mineral salt. Further, the artificial diet for lepidopteran insects is subjected to a treatment with a genetically engineered baculovirus.

Unmole (2009) utilized mungbean sprouts in the diet to mass rear *Maruca vitrata* Fab. larval survival was 87% in two generations and results were encouraging. One kilogram of mungbean yielded 1200 pupae. This revealed that locally available, preferred

host plant may be suitable as an ingredient in the diet. Blanco *et al.* (2009) worked on the diet with soybean and wheat germ flour for the tobacco budworm, *Heliothis virescences* (F.) and found that changes in the protein content and nutrients produced negative effects on the growth and development of the noctuid moth.

Maruca vitrata Fabricius is a serious legume pod borer. Chi *et al.* (2004) evaluated 12 artificial diets varying in proportions of constituents for suitability of mass rearing. The 30-50% cowpea diets and 30-70% azuki diets were the most suitable for mass rearing in view of their higher reproductive rates. OnYoungo and Ochieng'-Odero (1993) reared in laboratory *Maruca* for ten generations on soybean flour and cowpea flower powder as basic ingredients of the diet. One litre of diet produced on an average 400 pupae with adults having average fecundity of 200 eggs/female.

C. punctiferalis was successfully reared on an artificial diet consisting 150 g dried maize seeds, 6 g dried peach, 200 mg citric acid, 10 ml antiseptic, 9 g agar powder, 6 g rice bran, 3 g dehydrated yeast, 6 g sugar, 220 ml tap water and 2 g L- ascorbic acid per 100 larvae. The maize seeds should be soaked in tap water for one night before mixing with other ingredients. The antiseptic is a solution of 4 g methyl p-hydroxybenzoate and 1 g sorbic acid in 100 ml ethyl alcohol. The L-ascorbic acid should be added after the mixture has been autoclaved and cooled (Utsumi *et al*., 1990).

Workers have used different containers for mass rearing *C. punctiferalis.* Chakravarthy *et al.* (1992) utilized twelve different containers for rearing larvae of fruit feeding (FFT) and stalk-feeding types (SFT) of *Conogethes.* For FFT, polyvinyl cup (9.6 X 6.5 cm) proved to be the most suitable. For SFT, plastic rectangular boxes (21 X 11 cm) served as the best container. It may be noted here that species infesting castor has been identified as *C. punctiferalis* but that attacking cardamom as *Conogethes* species (Chakravarthy *et al.,* 2015). The container`s, relative net precision and efficacy and efficiency of larval rearing methods are as given in Tables 4 and 5. The study revealed that different species of *Conogethes* may require different rearing containers due to differences in larval behavior and host-plant relationships (Chakravarthy *et al.,* 1992).

Ambanna (2014) and Ballal *et al.* (1995) used sterilized glass vials (7 X 2.5cm) with different test diets. The vials were plugged with cotton (covered with black cloth to prevent escape of larvae) and one set up was reared on tender castor capsules placed in plastic containers (90×35×45cm) which served as control. The vials containing larvae reared on semi-synthetic diet were kept in a walk-in-chamber, where temperature was set at (26 ^{0}C), relative humidity at (70%) and light- dark hours (12:12). After 9-10 days the larvae were transferred to fresh diet. As per need (based on drying of diet), larvae were shifted to fresh diet. The pupae were collected and they were sexed and weighed and kept in different plastic boxes, such boxes were kept in a plastic container and relative humidity and temperature were maintained by providing wet sponge in the plastic container for adult emergence.

Honda *et al.* (1979) developed a simple mass rearing method for the fruit- feeding type yellow peach moth, *C. punctiferalis* with an oviposition device and an artificial diet. The oviposition device was ball-type tea strainer (dia. 8 cm) which contained a small green fruit as an odour source and was wrapped with cheese cloth. The artificial diet was composed of meal powder for mouse, soybean meal powder, ascorbic acid, water, wood powder and agar. The average cocoon yield was 39.40%, which was quite low. The comparison of *C. punctiferalis* growth and development on two artificial diets with natural foods.

The prepared artificial diet was sliced into small and thin pieces and placed into sterilized glass tubes (diameter by height, 2.4 by 7 cm) for rearing *Chilo suppressalis* Walker larvae, covered with sterilized cotton wool plug to allow air exchange but to prevent drying of the diet, pupae were extracted from rearing tubes, sexed and kept separately in plastic boxes for emergence (Han *et al.*, 2012).

2.6.2 Role of ingredients in artificial diets

The physical properties of the diet such as hardness, texture, homogeneity, water content and other factors that influence them should be considered. Physical modification of a diet may be accomplished by adding cellulose because it is not digested by insects. Its main purpose is to add texture to the diet so that insect will feed and provide roughage

which aids the passage of food material through the gut (Neville and Lucky, 1962). However, as amount of cellulose is increased, more of the thus diluted diet must be consumed to obtain the same amount of nutrients (McGinnis and Kasting, 1966). Hardness of a diet may be difficult to regulate because most plant feeding insects require high water content but need a firm surface against which they can press their mouth-parts. The polysaccharide, agar, is the preferred substance for controlling hardness because it is compatible with dietary ingredients, and in highly purified form is satisfactory for use in nutritional experiments (Vanderzant, 1974 and Singh, 1977).

Plant-feeding insects generally obtain high water requirement from food, although many insects can drink water, which is advantageous during periods of water scarcity (Singh, 1977). Large larvae of the salt marsh caterpillar, *Estigmene acrea* (Drury) fed readily on dry diet and obtained water by eating water-soaked filter paper (Vanderzant *et al.*, 1962). A change in water content affects the physical properties of the diet and changes the concentrations of the nutrients and also is difficult to maintain constant water content because of loss by evaporation (Singh, 1977).

There are several specific conditions required for particular insects such as presence of cracks and holes, raised areas on the surface, and curvature of the surface that could be considered as physical aspects (Singh, 1977). *Prodenia eridania* (Stoll) caterpillar would not feed on their diet unless it was cut narrow strips and laid out in a criss-cross manner, so that they could feed by placing themselves in gaps between the diets (Elliot, 1955).

The chemical composition of host plants significantly affects survival, growth and reproduction of phytophagous insects (Bernays and Chapman, 1994). Growth, development and reproduction in insects are closely related to the quality and quantity of food consumed (Scriber and Stansky, 1981). The *H. armigera* survival and development were adversely effected when the larvae were reared on diets containing leaf/pod powder of different chickpea genotypes. Chemical and nutritional factors of the food substrate determine consumption, development and survival (Singh and Mullick, 1997).

Castor oil is a rich source of ricinoleic acid, which is a monounsaturated fatty acid. Castor oil also contains moderate amounts of other fatty acids like oleic acid, linoleic acid, linolenic acid, palmitic acid and stearic acid (https://en.wikipedia.org/ wiki/Castor_oil). Cardamom is an excellent source of Vitamin C, Calcium, Magnesium, Potassium and Zinc, and a very good source of Dietary Fiber, Iron and Manganese (https://caloriebee.com/ nutrition/The-Nutritional-And-Health-Benefits-Of-Cardamom). Huang *et al.* (2000) reported that the contact and fumigant toxicities and antifeedant activity of the essential oil of cardamom, *E. cardamomum*, to two stored product insects, *Sitophilus zeamais* Motschulsky and *Tribolium castaneum* (Herbst), were investigated and reduced the hatching of *T. castaneum* eggs and the subsequent survival rate of the larvae.

The most significant component of cardamom, as spice, is the volatile oil with its characteristic aroma, described generally as comphory, sweet, aromatic spicy. The cardamom oil has few mono- or sesquiterpenic hydrocarbons and is predominantly made up of oxygenated compounds. While many of the identified compounds – alcohols, esters and aldehydes – are commonly found in many spice oils, the dominance of the ether, 1,8-cineole and the esters, α-terpinyl and linalyl acetates in the composition, make the cardamom volatiles a unique combination. The aroma differences in different sources of cardamom are attributed to the proportion of the esters and 1, 8-cineole (Wijesekera and Jayawardena, 1973; Korikanthimath *et al*., 1997).

Phagostimulants are compounds that release feeding behavior and induce insects to ingest (Dethier *et al.,* 1960). Continued feeding depends on the presence of feeding stimulants but not necessarily on the same ones in each stage. Phagostimulant compounds may be of nutritional value or may only provide token stimuli. Carbohydrates, proteins, amino acids, lipids, sterols, salts, vitamins, cellulose, agar, guanine monophosphate, terpenes and several organic aldehydes have shown phagostimulantory properties for insects (Singh, 1977). *Ostrinia nubilalis* (Hübner) larvae were stimulated mainly by glucose and to a lesser extent by fructose and sucrose (Beck, 1956). *Sesamia inferens* Walker reared on the South-western corn borer diet comprising wheat germ, corn cob grits, sucrose, casein (vitamin free), along with nine other ingredients including water. They studied the development of *S. inferens* on this diet and observed that on the basis of

different biological parameters, the South-western corn borer diet was better than rice stem for pink stem borer rearing of (Vega *et al.*, 1985).

Other phagostimulants are not of obvious nutritional value and many function as token feeding stimuli. Senthilkumar and Siddiqui (1993) compounded an artificial diet with green gram grain powder + maize grain powder + maize leaf, whorl, and tender stem powder as components of base-ingredients for the successful mass rearing of *S. inferens* in the laboratory. This diet was superior over the previously formulated diet based on green gram grain powder + wheat grain powder + maize leaf, whorl, and tender stem powder in completing development up to adult (moth) stage coupled with better sex-ratio. Sharma and Sarup (1978) tested nine artificial diets and identified lentil *(Lens culinaris* Medic.) grain-powder-based-diet as suitable for mass rearing *C. partellus.* Singh and Sarup (1987) have compounded an improved artificial diet by adding sorghum leaf factor with green gram + dew gram as principal base ingredients. Uma Kanta and Sajjan (1989) tested four diets with varying quantities of rajmah *(Phaseolus vulgaris)* for mass rearing C. *partellus* in Punjab.

Casein is a protein that facilitates as a source of energy and structural material in insects. Casein also serve as emulsifiers and bind water to form gels and films at interfaces among diet components. These unique properties of casein can change the consistency of the diet. So, casein is an essential ingredient in the preparation of artificial diets for insects (Bindu *et al.,* 2014).

For insect optimal growth and development in artificial diets, amino acids are required in adequate proportions (Panizzi and Parra, 1991). Casein has been widely used in insect artificial diets because it contains all the essential amino acids generally obtained from bovine milk, soluble in water, and does not coagulate upon heating (Parra, 1979). Casein also contains traces of fatty acids, cholesterol, sugars, vitamins, and minerals (Vanderzant, 1966). In the absence of one of the essential amino acids, or rather casein, growth and development was found incomplete in *Pectinophora gossypiella, Helicoverpa zea, Myzuz persicae, Tribolium confusum* and *Apis mellifera* (Hanife, 2004). Which are important pests of crops, worldwide. In fact, Salvador *et al.* (2010) found high insect

mortality with half concentration of casein in relation to the standard diet used for mass rearing *Anticarsia gemmatalis* Hübner, or without added casein.

Insects generally need a source for vitamins *viz*., thiamine, riboflavin, nicotinic acid, pyridoxine, pantothenic acid, folic acid, and biotin, in small amounts, because insects can't synthesize the vitamins (Hanife, 2004). Vitamins often have a role as cofactors of the enzymes catalyzing metabolic pathways. Vitamin E is an antioxidant, fat-soluble and therefore, it is stored in the body tissues and used when needed (https://www. noorvitamins.com/Health-Blog/vitamin-e-type-facts-benefits-halal/). Vitamin E although required in micro quantities, is essential for reproduction in insects, and enhances the fecundity (McFarlen, 1992). For example, vitamin E at 200 mg/ 400ml diet in the artificial diet resulted in higher larval and pupal survival and adult emergence. The fecundity of the *H. armigera* increased with an increase in Vitamin E in the artificial diet (Chitti Babu, 2012).

Another study by Zwołińska-Śniatałowa (1976) from Poland, revealed the influence of alpha-tocopherol on the Colorado potato beetle (*Leptinotarsa Decemlineata* Say), showed that the most important differences occur in insect reproduction. The adult females laid an increasing quantity of eggs when higher doses of alpha-tocopherol were administered. Histological studies revealed that a higher quantity of sperm was present in the gonads of the males fed on increased doses of alpha-tocopherol. Oocytes had thick follicular epithelium comprising large cells than in untreated adults.

Generally, the presence of microorganisms in an artificial diet cause spoilage of the diet and is detrimental to insects (Singh and Bucher, 1971). Microbial contamination is one of the major problems affecting the rearing of insects. Bacterial and fungal contaminants from insectary-reared insects were reviewed by Sikorowski and Lawrence (1994). Funke (1983) has reviewed the mold control for insect rearing media, while Dunkel and Read (1991) have reviewed the effect of sorbic acid on insect survival in diets with reference to other antimicrobials. Microbial contamination in insect artificial diet is often problematic with *Aspergillus niger*, *Aspergillus flavus*, *Cladosporium* spp., *Fusarium* spp., *Rhizopusnigricans*, *Penicillium* spp. and yeasts and bacteria (Zha and Cohen, 2014). Suppressing microbial growth in artificial diets is key to the success of mass rearing.

Antimicrobial substances are often used in larval diets and eggs are treated with antimicrobial washes. Before development of methods of egg surface sterilization (Getzin, 1962; Ignoffo, 1963; Paschke, 1964) and artificial diets containing microbial agents, high larval mortality resulting from nuclear polyhedrosis virus severely limited the rearing of insects on artificial diets. Roeder *et al.* (2010) conducted studies on an antimicrobial agent, Diet Antimicrobial Agent (DAA) (Composed of five ingredients *viz*., propionic acid, phosphoric acid, sorbic acid, benzoic acid and chloramphenicol), and evaluated ability to suppress microbial growth against strains of *Heliothis virescens* Fabricus at Texas, USA. The results suggested that DAA is an effective suppressor of microbial growth on artificial diets.

The need to supplement the diets with anti-microbial substances *viz.,* formaldehyde, methyl-p-hydroxybenzoate, butyl-p-hydroxybenzoate, dichlorophene, pimaricin, chlorotetracycline, kanamiycin, di-hydrostreptomycin sulfate and sodium propionate is to inhibit the growth of fungi, yeast or bacteria (Singh and House, 1970; Krieg, 1971 and Singh 1977). Benzoic acid, formalin, and sorbic acid are commonly used antimicrobial agents the growth of *Aspergillus niger* in the artificial diet of *Lygus hesperus* Knight. Propionic acid and lower concentrations of sorbic acid and formalin were less effective in suppressing A. *niger* growth. Biological fitness was negatively affected in insects reared on diets containing high levels of *A. niger*, and in diets with high concentrations of formalin (Alverson, 2003). Alternative methods of checking microbial contamination in diets, such as adjusting the pH or by sterilizing the diets and equipment should be considered (Singh, 1977). Greenberg (1970) dealt with sterilizing procedures and agents, antibiotics and inhibitors in mass rearing insects.

2.6.3 Diet performance

Ambanna (2014) found that larval period of *C. punctiferalis* on cardamom leaf semi-synthetic diet, plain diet, maize diet, castor diet and natural diet was 30.42±1.10, 26.10±1.2, 23.6±0.80, 23.5±0.70 and 21.50±0.95 days, respectively and pupation lasted for 11.6±0.40, 10.8±0.40, 10.6±0.35, 10.4±0.40 and 9.6±0.20 days, respectively and adult longevity on an average with mean of 9.0±1.0, 8.5±0.5, 8.7±0.540, 8.9±0.3 and

8.8±0.4days, respectively. Yathish (2012) revealed that when the *Conogethes* reared on castor, colour of the pre-pupae was light greenish with distinct dark spots over the body. The pre pupal length varied from 13.2 to 13.8 mm with an average of 13.4 mm and width range from 2.4 to 2.7mm with an average of 2.5 mm, pre pupal period lasted from 2.25 to 2.88 days. The pupa was brownish yellow with dark compound eyes later turned into light brown. Pupal length varied from 11.2 to 11.8 mm with an average of 11.48 mm and width varied from 2.7 to 2.9 mm with an average of 2.78 mm. The pupal period lasted for 9.50 to 12.00 days in Nagpur, Central India.

The Asiatic rice borer, *C. suppressalis* reared on the artificial diet showed better performance with shorter developmental stage, similar larval survival rate and fecundity and heavier pupae compared with that fed on rice plants and fresh water bamboo. A positive correlation was observed between number of eggs laid per female and number of generations reared on the artificial diet. Larval development time tended to be shortened with successive rearing on the artificial diet (Han *et al*., 2012).

Seven artificial diets were prepared by substituting basic ingredients as flour of chickpea, mungbean, soybean, wheat, maize, cotton seed, water and chestnut tested for rearing *Helicoverpa armigera* in laboratory and compared with natural food comprising of chickpea leaves and pods. Chickpea flour mediated diet produced healthy larvae and pupae that gained the maximum weight measuring 0.4500 and 0.3805 g and completed development within the minimum duration of 14.5 and 11 days, respectively. Larval mortality was maximum on cotton seed flour followed by flours of water chestnut, soybean and wheat. However, mortality of *H. armigera* was minimum and non significant ranging from 1.1 to 1.3 per cent in flour of chickpea, mungbean and natural chickpea leaves and pods apparently normal adult emergence of 91.6 per cent was achieved on chickpea flour, 85.5 per cent on mungbean, 83.1 per cent on chickpea leaves and pods and 82.5 per cent on soybean (Hamed and Nadeem, 2008).

2.7 Pheromone

In insects, chemosensation serves to detect and react to environmental chemical cues, in virtually every aspect of their life cycle (Field *et al.*, 2000 and Pitts *et al.*, 2011).

Olfaction, as a kind of chemosensation, is critical to food source identification, predator avoidance, oviposition site selection, kin recognition, mate choice, and toxic compound avoidance. The power of olfactory communication has been witnessed by anyone who has seen how male dogs locate a bitch in heat or how the odor of a virgin female moth will draw males from great distances (Regnier and Law, 1968). As early as 1837, Siebold and Von recognized that the odours emitted by female insects, probably were attractants for males of the same species and that the odours secreted by male insects were aphrodisiac that incited females to mate. Fabre (1904) verified that caged female of great peacock moth, *Saturnia pyri* (Linnaeus) attracted a large number of male moths. He accepted that insects detected the odours of other insects, but he could not believe that such odours operated over long distances. Presently, several olfactory-based strategies have been developed to control moth populations, such as mass trapping and mating disruption through pheromones (Witzgall *et al.*, 2010). During the recent years, the olfactory communication systems of the yellow peach moth have received considerable attention because of their potential in population outbreak monitoring and pest controlling.

The name "Pheromones" was proposed by Karlson and Butenandt (1959), for the chemical compounds that cause one or more specific reactions in a receiving organism of the same species i.e., sexual attraction, alarm, aggregation or sex determination at maturity. The term pheromone was derived from the Greek “pherein” (to carry) and “horman” (to excite, stimulate) (Regnier and Law, 1968). Many types of pheromones viz., sex, aggregation, alaram, parapheromone, trail pheromone have a common cause acting cues to trigger response of their partner. However, the sex pheromones are associated with singling sexual behavior by releasing odurs to find genetically different mates and avoid inbreeding (Bernstein and Bernstein, 1997).

The first insect sex pheromone to be isolated and chemically characterized by Butenandt *et al.* (1959) from the commercial silk worm, *Bombyx mori* L. These investigators, without the benefits of chemical instrumentation, now so widely available, isolated and identified a single compound trans-l 0, cis-12, hexadecadien-l-01 by fractionating the complex mixture from an extract of the secretary gland. There was a rapid growth in the identification of insect pheromones during 1970s and by the end of 1980s

pheromones and pheromone mimics were known for over 1000 species of insects (Jones *et al.*, 2008).

Sex pheromones are mostly produced by females and in some case by males, according to species (Hildebrand, 1995). Since the identification of the first insect pheromone there has been a continuing interest in behaviour-modifying chemicals and their potential role in integrated pest management. Pheromones are used commercially in two main ways for indirect control (surveying or monitoring the pest population so that chemical control measures can be undertaken at the appropriate time) and for direct control (mating disruption, mass trapping or lure and kill) (Minks, 1977; McVeigh *et al.*, 1993; Jutsum and Gordon, 1989; Hall, 1995). Today, it is considered that sex pheromones in insects contain mixtures of several compounds, of which the primary component attracts the insects upwind from a distance and the secondary components in combination with the primary component stimulate aspects of mating behavior (Piccardi, 1979).

In the present study the pheromonal component was included to evaluate the identified sex pheromone component of *Conogethes* and standardization of the sex pheromone traps under field conditions. The reviews on pheromone component of *Conogethes* are presented in detail.

Sex pheromone composites of *C. punctiferalis* have been analyzed, synthetized and made into lure to attract male moths and disrupt their mating in fields (Konno *et al.*, 1982; Liu *et al.*, 1994; Xiao *et al.*, 2012; Du *et al.*, 2014b). In Japan, sex pheromone was extracted from the abdominal tips of females of the fruit-feeding type of *Dichocrocis punctiferalis* (Gn.). It was identified by gas liquid chromoatography, mass spectrometry, ozonolysis and electroantennography as (E)-10- hexadecenal. The synthetic compound was attractive to males of the species (10 ng being equivalent to 1 live virgin female) in the laboratory, but in the field, traps baited with this compound caught only a few males. Among which, (E)-10-hexadecenal (E-16:Ald) was considered as principal component of pheromones, whereas (Z)-10-hexadecenal (Z-16:Ald) as secondary component, and the field trapping effect was best when the ratio of these two components was 9:1 at the dose of 300.0 ug/lure (Konno *et al.*, 1982). About ten years later, hexadecanal (16:Ald) was identified as another

secondary component, and the field trapping effect was improved when the ratio of 16:Ald, Z-16:Ald and E-16:Ald was 16:8:100 at the dose of 250.0 ug/lure (Liu *et al.,* 1994).

Konno (1986) investigated the relationship between the daily changes in the sex pheromone quantity and calling behaviour in females of *Conogethes punctiferalis* in the laboratory at 23 ºC, 70-80% RH and LD 15:9. He recorded that quantity of the sex pheromone, (E)-10 hexadecenal, in the pheromone gland increased when the lights were turned off, reached a maximum after 5 h and then decreased. On the other hand, calling started from 5 h after light-off, reached a maximum 7.5 after light-off and then decreased. Mori *et al.* (1990) studied the synthesis and biological evaluation of 2 sex-pheromone mimics ((E) - and (Z)-Tetradecenyl formate) for the polyphagous pest *C. punctiferalis* are described. A 10:1 mixture of (E) -and (Z)-tetradecenyl formate was found as attractive as the natural pheromone for adults of the pyralid.

Mori *et al.* (1990) found that "a 10:1 mixture of the (E)- and (Z)-formats was shown as attractive as a 10:1 mixture of (E)- and (Z)-10- hexadecenal (genuine pheromone) in a 100-µg dose against this pest. Cai and Mu (1993) reported that traps consisting of plastic bowls filled with water below a pheromone dispenser (containing 250 µg) significantly reduced damage caused by *C. punctiferalis* in 2 citrus orchards, at 4 traps/0.23 hm^2, in China. There seems to be a difference in attraction between populations as this pest seems to consist of two different populations in the northeastern Asia region, with one group responding to the blend of 100: 8-100:11 between (E)-10-hexadecenal and (Z)-10-hexadecenal and the other to that of 100: 43. The first group was found in Japan and China and the second in Korea and China (Boo 1998).

Liu *et al.* (1994) identified (Z)-10-hexadecenal (Z10-16: Ald) and hexadecenal (16: Ald) are two minor components along with the major component, (E)-10-hexadecenal (E10-16: Ald), of the sex pheromone of the pyralid *C. punctiferalis*. Analysis of single sex pheromone gland extracts by capillary gas chromatography indicated that the relative ratio of 16: Ald, E10-16: Ald and Z10-16: Ald was 13.0: 80.4: 6.6. Field trials in Shandong, China, in 1987 indicated that Z10-16: Ald and 16: Ald alone caught no males. The most

attractive was a blend containing 16: Ald, E10-16: Ald, and Z10-16: Ald at a ratio of 16: 100: 8, and a two compound blend of E10-16: Ald and Z10-16: Ald at a ratio of 100: 8.

Chakravarthy and Thyagaraj (1997) studied the activity of 7 pheromone compounds ((Z)-9-hexadecenyl acetate, (Z)-7-tetradecenal, (E)-11-tetradecenal, (Z)-11-tetradecenal, (Z)-11-hexadecenal, (E)-10-hexadecenal and (Z)-10-hexadecenal) against *C. punctiferalis.* Tests were carried out in the laboratory and in cardamom fields in Mudigere and Sakleshpur, India, during September-December 1985-93. In the laboratory, males responded to (E)-10-hexadecenal, (Z)-10-hexadecenal and (Z)-11-hexadecenal at 1000 ng. A blend of (E)-10-hexadecenal and (Z)-10-hexadecenal at 9:1 had maximum attractancy. Field trials with this blend gave positive results. Laboratory studies on the mating behaviour of *C. punctiferalis* showed that an airborne sex pheromone is released from the calling female. Males were attracted to virgin female extract in the laboratory tests suggesting that the extract contained pheromone components for their attraction. (E)-10-hexadecenal and (Z)-10-hexadecenal at 1000 ng concentrations when tested separately, and a blend of these two compounds at 9:1 attracted the maximum number of male moths in the laboratory.

Chakravarthy and Thyagaraj (1998) trapped this species using 9:1 for (E)-10-hexadecenal and (Z)-10- hexadecenal in the field trails in Karnataka, India. This blend has been used for mass-trapping, monitoring, and mating disruption in Japan, Korea, and China (Kimura and Honda, 1999). In Korea, an 80:20 ratio of (E)-10-hexadecenal and (Z)-10-hexadecenal had the highest attractiveness in orchards (Jung *et al.,* 2000). Further work by Xiao *et al.* (2012) found that certain hydrocarbons had a synergistic effect on responses to pheromones. (E)- and (Z)-8-tetradecenyl formate have been synthesized and tested for effectiveness in trapping *C. punctiferalis*.

Boo (1998) investigated the variation in sex pheromone composition of *D. punctiferalis* and seemed to consist of two populations in Northeastern Asia, with a group found in Japan and China responding to a 100:8 to 100:11 blend of (E)-10-hexadecenal and (Z)-10-hexadecenal and a group in Korea and China to a ratio of 100:43. Kimura and Honda (1999) identified (E)-2-methyl-2-butenoic acid (tiglic acid) from male hairpencil

scent of *C. punctiferalis* by GCEAD, GC and GC-MS analysis. They also studied the function of tiglic acid and concluded that it act as a sex pheromone in conspecific male recognition and also may be important as an aphrodisiac pheromone.

Jung *et al.* (2000) conducted behavioral and field trapping studies to develop a monitoring system with its sex pheromone. Virgin females displayed maximum mating behavior and hairpencil extrusion behavior between 4-5 hrs after the absence of light under a 16 L/8 D photoperiod and 26±1º C. Two sex pheromone components, E10-hexadecenal and Z10-hexadecenal, were detected by GC analysis in the hexane extract of abdominal tips of virgin females during calling period. In wind tunnel studies the pheromone blend 70:30 ratio of E10-hexadecenal and Z10-hexadecenal gave best response for hair pencil extrusion and at the 80:20 ratios for the flying upwind response. The highest attractiveness in fields was obtained between 70:30 and 80:20 from several tests in orchards.

Kimura *et al.* (2002) studied the distribution of tiglic acid as a male pheromone in the hair-pencil complex and microstructures of the constitutive hair scales in the yellow peach moth, *C. punctiferalis*, collected from *Pinus parviflora* (Farjon) in Tsukuba, Ibaraki, Japan. Identified hairpencils which were found in a pair of cuticular pockets located bilaterally at the base of the genitalia, and named as phylliform (PHS), supatulate (SHS), filiform (FHS) and retiform hair scales (RHS). Selective GC analysis of extracts of the four types of hair scales revealed that fluff hair scales (FHS+RHS) exclusively contained tiglic acid. Scanning electron microscopy showed that RHS have characteristic structures for release of pheromonal scent or "osmophores". It was confirmed that males of *C. punctiferalis* discharged their osmophores when they responded to the female sex pheromone. Tiglic acids as well as other scent chemicals were not detected from the hair-pencils of its sibling species, *Conogethes* sp. by gas chromatogram electro-antennogram recordings, although they have the same types of hair scales. They have concluded that tiglic acid involved in inter- and intraspecific male recognition in the final steps of courtship behaviour of these two species. Song *et al.* (2008) synthesized Z/E-10-Hexadecenal by Wittig reaction and the field experiments showed that the sex pheromone had the best effect when the dose was 50.0 µg/bait at Z/E 20/80.

Xiao and Honda (2010) studied the synergistic effects of a non-polar fraction (NPF) from the crude pheromone extract on the activity of a polar fraction (PF), including aldehydes in wind tunnel. The findings were, NPF itself showed no activity, but the number of males attracted close to the source significantly increased when it was added to PF. Similar synergistic effects were also observed in a female body wax (FBW) extract and its NPF but not in male body waxes. Effects of NPF from both sources dose-dependently increased and the active dose range of NPF in FBW was larger than that of the crude pheromone extract. New unknown components that synergistically improve the activity of aldehyde components may be non-polar compounds in FBW. They concluded that actual sex pheromone system of the yellow peach moth may consist of aldehydes (attractive over a long distance) and non-polar components in female body wax that functions as a cue for the final recognition of females.

A blend of E-10-hexadecenal and Z-10-hexadecenal at 90:10 ratio was the most attractive *Conogethes* species in the field (Rajabaskar and Regupathy 2012). Recently, 16 formulations of sex pheromones and corresponding lures were developed with different compositions, ratios and dosages of (E)-10-hexadecenal (E-16:Ald), (Z)-10-hexadecenal (Z-16:Ald), and hexadecanal (16:Ald), and the field trapping tests were conducted to investigate their efficiencies. The results showed that the number of moths trapped by formulation D400-1:4 ((Z-16:Ald): (E-16:Ald)=1:4 and the dose used was 400.0 μg) was the highest among the 16 tested formulations (Du *et al.*, 2014b). A comparative study was conducted on the efficiency of different doses, lure color, number and types, as well as hanging height of traps on capture of *C. punctiferalis.* The results showed that water barrel trap with a lure of Zhongjie Company and hung it in the middle of crown could reach to the best trapping effect (Ren and Guo, 2015).

Response to two main sex pheromone components were identified as E-10 Hexadecenal and Z-10 Hexadecenal and their ratios tend to vary in natural conditions and female body wax was observed to be synergist in improving the field efficacy of sex pheromone (Sithanantham *et al.,* 2013). Honda (2013b) separated female body wax by a column chromatography and five monoenyl hydrocarbons showed synergistic effect thus concluding that sex pheromone set for yellow peach moth consisted of E10-16:Ald, Z10-

16:Ald for a long range attraction and Z9-27:CH, Z3Z6Z9-23:CH for the final recognition of females by males in near-pheromone source. A blend of (E)-10-hexadecenal (E10-16: Ald) and (Z)-10-hexadecenal (Z10-16: Ald) in 95.4: 4.5 was less effective than pheromone extracts and can be improved by adding non-polar fractions (NPF). Therefore, Honda and Wei (2015) concluded that a full set of sex pheromone system is more efficient in capturing yellow peach moth males for a long range and near pheromone source attraction. Sithanantham (2015) stated that improving trap would facilitate moth catches.

In Malaysia, GC analysis of the pheromone extract on the polar DB23 column confirmed the presence of four compounds with retention times similar to that of hexadecenal isomers (Sivapragasam, 2004). Singh and Kaur (2016) tried trapping of *Conogethes* males on peach, pear, guava, mango and litchi orchards using commercial pheromones for *Conogethes* in cardamom and ginger but did not get any trap catches.

III MATERIAL AND METHODS

The material used, and the techniques employed on aspects of mass rearing, seasonal incidence and pheromones for the investigations entitled "Standardization of mass rearing technique and field evaluation of pheromone of shoot and capsule borer, *Conogethes* spp (Lepidoptera: Crambidae) on selected host plants" are described in this chapter. Seasonal incidence and field evaluation of the pheromone components of the shoot and fruit borer, *Conogethes punctiferalis* Guenée on selected host plants were conducted at the Dryland Research Station, University of Agricultural Sciences (UAS), Gandhi Krishi Vignana Kendra (GKVK), Bengaluru ($13^0$05"N, $77^0$34" E with 924m MSL); Bio-Control Research Laboratories (BCRL), Sriramanahalli, near Rajankunte, Bengaluru; fields of local farmers cultivating castor at Pavagada, Tumkur (District) (14.1°N, 77.27°E with 646m MSL), Zonal Agricultural and Horticultural Research Station(ZAHRS), Babbur farm, Hiriyur, Chitradurga (Dist.) (13.95°N, 76.62°E with 630m MSL) and cardamom fields at Mudigere, Chikkamangalur (Dist.) (12°25'N; 75°43'E and 980m MSL), Karnataka, India during 2015-17. The details of experimental procedures followed in the present investigations have been described under the following heads:

3.1 Seasonal incidence of *C. punctiferalis* and *C. sahyadriensis* on select host plants

Several surveys were conducted to determine the scenario of *C. punctiferalis and C. sahyadriensis* on select host plants at different locations during 2015-17 (Table 4). Observations were made at fortnightly intervals on the number of infested shoots and fruits per fifteen plants throughout the year for recording the seasonal abundance and the peak activity period of these insect pests. The observations were recorded from fifteen randomly selected plants from each plot. The per cent damage was estimated by counting both damage and total number of capsules/fruits and shoots. Data on weather parameters *viz.*, maximum and minimum temperature, sunshine hours, rainfall and relative humidity were correlated with incidence of *C. punctiferalis and C. sahyadriensis* and regression equation were also worked out.

$$\text{Capsule/fruit damage (\%)} = \frac{\text{Number of damaged capsules/fruits}}{\text{Total number of capsules/fruits}} \times 100$$

$$\text{Shoot damage (\%)} = \frac{\text{Number of damaged shoots}}{\text{Total number of shoots}} \times 100$$

Table 4. Seasonal incidence of *C. punctiferalis and C. sahyadriensis*

Host plants	Locations
Castor bean (*Ricinus communis* L.)	• Local farmer (Rajanna) field, Gangasagar, Pavagada, Tumkur (Plate 1) • Zonal Agricultural and Horticultural Research Station (ZAHRS), Babbur farm, Hiryur, Chitradurga • Dryland Research Station, UAS, GKVK, Bengaluru
Cardamom (*Elettaria cardamomum* L.)	• Local farmers (Satish farm) field, Mudigere (Plate 2) • Zonal Agricultural and Horticultural Research Station (ZAHRS), Mudigere
Ginger (*Zingiber officinale* Roscoe)	• Local farmers fields, Hassan (Plate 3) • Local farmers fields, Shikaripur, Shivamogga • Local farmers fields, Kodagu

3.2 Technique for mass rearing *Conogethes punctiferalis* and *Conogethes sahyadriensis*

Studies on standardization of mass rearing technique for shoot and fruit borer, *C. punctiferalis* and *C. sahyadriensis* were conducted during 2015-17 under laboratory conditions at the Division of Entomology and Nematology, ICAR-Indian Institute of Horticultural Research (IIHR), Hessaraghatta, Bangaluru ($13^0$8.12”N, $77^0$29.45”E with 890m MSL) with following sub-headings.

3.2a Effect of plant factor on the development of *C. punctiferalis* and *C. sahyadriensis* reared on artificial diets

3.2b Effect of Casein on growth and development of *C. punctiferalis* and *C. sahyadriensis* reared on artificial diets

3.2c Effect of Vitamin E on fecundity of *C. punctiferalis* and *C. sahyadriensis* reared on artificial diets

3.2d Effect of anti-microbial ingredients on growth and development of *C. punctiferalis* and *C. sahyadriensis* reared on artificial diets

The materials used, and methodologies followed for mass rearing is as described below:

3.2.1 Test Insect

The shoot and capsule borers, *C. punctiferalis* on castor and *C. sahyadriensis* on cardamom were the test insects. The initial cultures of the pests were established with a collection of C. *punctiferalis* larvae from infested castor field (Plate 1) at the Dryland Research Station, University of Agricultural Sciences, GKVK, Bengaluru ($13^0$05" N, $77^0$34" E with 924m MSL), and *C. sahyadriensis* larvae from infested cardamom field (Plate 2) at the College of Horticulture and local farmers fields at Mudigere, Chikamagalur (Dist.), Karnataka, India during 2015-17. The borer population was maintained on fresh castor and cardamom for one generation. The stock borer culture was held in laboratory under the 26±1^0C, 70-80% relative humidity, and a photoperiod of 16:8h light: dark. Ten pair of moths (male and female in equal number) was released inside the oviposition cage (ventilated glass cage, 60x60x60cm) for oviposition. The Red light was provided in the chamber with 15W (decoration) red lamp fixed from the top or hung between two cages. Red light is known to be essential as stimuli for mating and laying fertile eggs. The eggs of *C. punctiferalis and C. sahyadriensis* were used for conducting experiments during present investigations.

3.2.2 Ingredients of Artificial diets

a) Powders and host plants

The different commercially available powder of Bengal gram and host plant parts used in the formulation of artificial diets are presented in Table 5.

Table 5. Commercially available powders and host plant parts used in artificial diets

Diet base	Botanical name	Family	Functions
Powders commercially available			
Bengal gram powder	*Cicer arietinum* L.	Leguminaceae	As a main ingredient/carrier
Host plant parts			
Castor capsule	*Ricinus communis* L.	Euphorbiaceae	As a token stimuli to initiate and maintain continuous feeding
Cardamom leaf	*Eletteria cardamomum* Maton.	Zingiberaceae	As a token stimuli to initiate and maintain continuous feeding

b) Chemicals: The chemicals used other than base ingredients of artificial diets are given in Table 6.

Table 6. Chemicals used in artificial diet

Name of the chemicals	Source of supply	Functions
Yeast powder	RM027-500G, HiMedia Lab. Pvt Ltd.	Source of proteins and vitamins
Casein	GRM497-500G, HiMedia Lab. Pvt Ltd.	A protein source which provides amino acids and carbohydrates for tissues
Sucrose	GRM134-500G, HiMedia Lab. Pvt Ltd.	As a source of sugar
Distilled water	-	As a solvent for diet ingredients
Agar-agar	GRM666-500G, HiMedia Lab. Pvt Ltd.	Solidifying agent
Ascorbic acid	PCT0207-100G, HiMedia Lab. Pvt Ltd.	Normal growth and development, egg hatching and pupal formation
Wesson's salt mixture	TS1100, HiMedia Lab. Pvt Ltd.	As source of salt required to maintain membrane structure and function
Sorbic acid	FD236-0.200g, HiMedia Lab. Pvt Ltd.	As preservative for the diet, so that it does not deteriorate
Multivitamin multimineral capsules	BECADEXAMIN, GlaxoSmithKiline. Pvt Ltd.	As a source of Vitamins
Methyl parahydroxy benzoate	GRM1291-500G, HiMedia Lab. Pvt Ltd.	As food and flavor ingredient, stimulant
Streptomycine sulphate	CMS220-5G, HiMedia Lab. Pvt Ltd.	As an antibiotic for reducing microbial contamination
Vit. E capsule USP 400mg	Evion 400, MERCK Ltd.	As a source of vitamins for reproduction of insects

Plate 1. Nature of damage and symptoms of *C. punctiferalis* on castor

Plate 2. Nature of damage and symptoms of *C. sahyadriensis* on cardamom

Plate 3. *C. sahyadriensis* infestation on ginger crop

Blender (Sumeet Domestic Plus 2000 Mixer Grinder), hygrothermograph, electric mettler balance (Mettler Toledo™ MS-TS Analytical Balance), rearing plastic vial (5 x 4 cm), plastic boxes (15 x 6 cm), ventilated glass cages (60 x 60 x 60 cm), microscope (Nikon SMZ25, 1x, WD: 60), petridishes (10cm dia x 1.5 cm ht), measuring cylinders (100ml and 500ml capacity), cotton, camel hair brushes, rubber bands, glass marking markers, hand lens (10X), beaker (500 ml), black cloth, white butter paper and spatula.

3.2.3 Diet preparation:

The semi-synthetic diet formulated for *C. punctiferalis* (Ambanna, 2014) was used as a starting medium for preparation of meridic diet for shoot and capsule borer and the diet was modified by the addition of token stimuli, casein and Vitamin E. The efficacy of three different artificial diets A to C were compared with natural food (Diet D- fresh castor capsule/cardamom shoot) for the successful rearing of shoot and capsule borer, *C. punctiferalis* and *C. sahyadriensis.* The composition of artificial diets and method of preparation are mentioned below.

Diet A:

This diet was developed for rearing larvae of shoot and capsule borer. The main ingredients of this diet were castor capsule powder added as a token stimulus (Table 7; Plates 4).

Preparation of diet A:

The ingredients for the diets were divided into three parts (A, B&C) as shown in Table 7.

Part A: The ingredients were weighed and kept separately before mixing. Fresh castor capsules were grounded in a grinder mixer at 2800 rpm for 5 min to form a powder. It was homogenized with 325 ml water in a blender. The homogeneous mixture was mixed with Bengal gram powder, casein, yeast extract powder and sucrose in a stainless steel pot. The mixture was autoclaved for 30 min at 125^0C. **Part B:** Agar with 300ml distilled water was heated to boiling to dissolve it completely. At this point, this part was poured into part

A, blended for 3min, and allowed to cool for future use. **Part C:** The weighed ascorbic acid, Wesson's salt, sorbic acid, multivitamin- multimineral capsules, vitamin E, methyl parahydroxy benzoate and streptomycin sulphate were dissolved in 75 ml distilled water. The solution was added to the mixture of part A and B and blended for 3min. The prepared and slightly luke-warm viscous diet mixture was poured into the plastic vials (5 x 4 cm) filling 3/4th the volume (Plate 4) and sealed with plastic cling cap, and the diet was allowed to solidify at room temperature (Plate 5).

Table 7. Composition of ingredients in the artificial diets (Diets A-C)

Parts	Ingredient	Quantity (gm / ml)		
		Diet-A	**Diet-B**	**Diet-C**
A	Bengal gram powder (Commercially available)	115.00	115.00	185.00
	Castor capsule/leaf powder (Locally prepared)	**85.00**	**-**	**-**
	Cardamom capsule/leaf powder (Locally prepared)	**-**	**85.00**	**-**
	Yeast powder	25.00	25.00	25.00
	Casein	35.00	35.00	35.00
	Sucrose	15.00	15.00	15.00
	Distilled water	325.00	325.00	330.00
B	Agar-agar	15.00	15.00	15.00
	Distilled water	300.00	300.00	300.00
	Ascorbic acid	3.00	3.00	3.00
C	Wesson's salt mixture	1.50	1.50	1.50
	Sorbic acid	1.00	1.00	1.00
	Multivitamin, multimineral capsules	2.00	2.00	2.00
	Methyl parahydroxy benzoate	2.00	2.00	2.00
	Strepomycine sulphate	0.50	0.50	0.50
	Vit. E capsule USP 400mg	1.00	1.00	1.00
	Distilled water	75.00	75.00	80.00

Values show the quantities for 1000g artificial diet, Diet-A (Bengal gram powder and castor capsule/leaf powder-based diet), Diet-B (Bengal gram powder and cardamom capsule/ leaf powder-based diet) and diet C (Bengal gram powder and without any token stimulus-based diet)

Diet B:

This diet was formulated for rearing larvae of shoot and capsule borer. The main ingredients of this diet were Bengal gram powder (*Cicer arietinum* L.) and cardamom leaf powder (Table 7; Plates 5).

Preparation of diet B:

Cardamom leaf powder was prepared by chopping cardamom leaf into small bits, drying them in the hot air oven and then powdering them in the grinder mixer at 2800 rpm for 5 min. Locally available gram and cardamom powders were stored in air tight plastic container.

All the ingredients mentioned in Table 7 were weighed accurately using electronic balance. Cardamom leaf powder was homogenized with 325ml water in a blender. The homogeneous mixture was mixed with Bengal gram powder, casein, yeast extract powder and sucrose in a stainless steel pot. The mixture was autoclaved for 30 min at 125^0C. Agar with 300ml distilled water was heated to boiling to dissolve the agar completely. At this point, this part was poured into part A, blended for 3min, and allowed to cool for future use. The weighed ascorbic acid, Wesson's salt, sorbic acid, multivitamin multimineral capsules, vitamin E, methyl parahydroxy benzoate and streptomycin sulphate were dissolved in 75 ml distilled water. The solution was added to the mixture of part A and B, mixed in the blender, while stirring to ensure thorough mixing. Finally, the diet was poured in the plastic vials (5 x 4 cm) filling $3/4^{th}$ the volume and sealed with plastic cling cap (Plate 5).

Diet C:

The diet C was prepared without addition of any token stimulus (castor/cardamom) and the main basic ingredients was Bengal gram powder (Table 7; Plates 6).

Preparation of diet C:

The procedure for preparing diet C was same as that for diet A and B. The quantities of ingredients mentioned in Table 7 were used for preparation of diet C. The agar was

boiled with water (fraction B) and mixed with fraction A, blended for 2 min. This mixture was blended with fraction C and the blender was run for 2 min. Finally, the diet was poured in plastic vials (filling 3/4th the volume) for proper setting (Plates 6).

Diet D: Natural food (castor capsules and cardamom shoots):

Castor panicle with flowers and young capsules, and cardamom young shoots are natural food for the larvae of shoot and capsule borer, *C. punctiferalis* and *C. sahyadriensis,* respectively (Plate 7). The castor panicle with flowers and young capsules were collected from castor fields grown at Dryland Research Station, University of Agricultural Sciences, GKVK, Bengaluru and cardamom young shoots were collected from fields of cardamom at College of Horticulture, Mudigere, Chikamangalur, Karnataka, India.

3.2a Effect of plant factor on the growth and development of *C. punctiferalis* and *C. sahyadriensis*

Studies were undertaken to assess the effect of addition of young capsules of castor and cardamom on growth and development of *C. punctiferalis* and *C. sahyadriensis,* respectively. The details of different diet combinations tested for *C. punctiferalis* and *C. sahyadriensis* are given in Tables 8 and 9.

Plate 4. Artificial diet A (Castor capsule/ leaf powder-based diet) glass container with *Conogethes* larvae

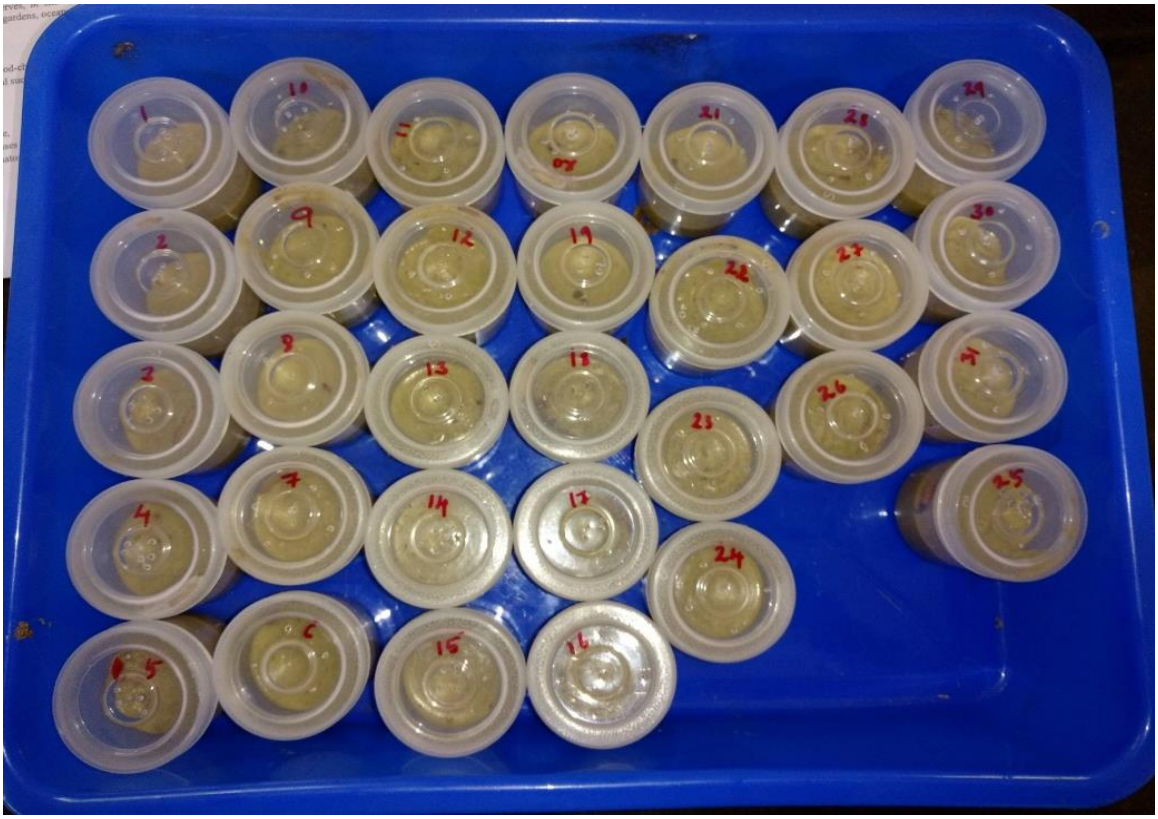

Plate 5. Artificial diet B (Cardamom capsule/ leaf powder-based diet) in the capped plastic cups with *Conogethes* larvae

Plate 6. Artificial diet C (Without token stimulus-based diet) glass container with *Conogethes* larvae

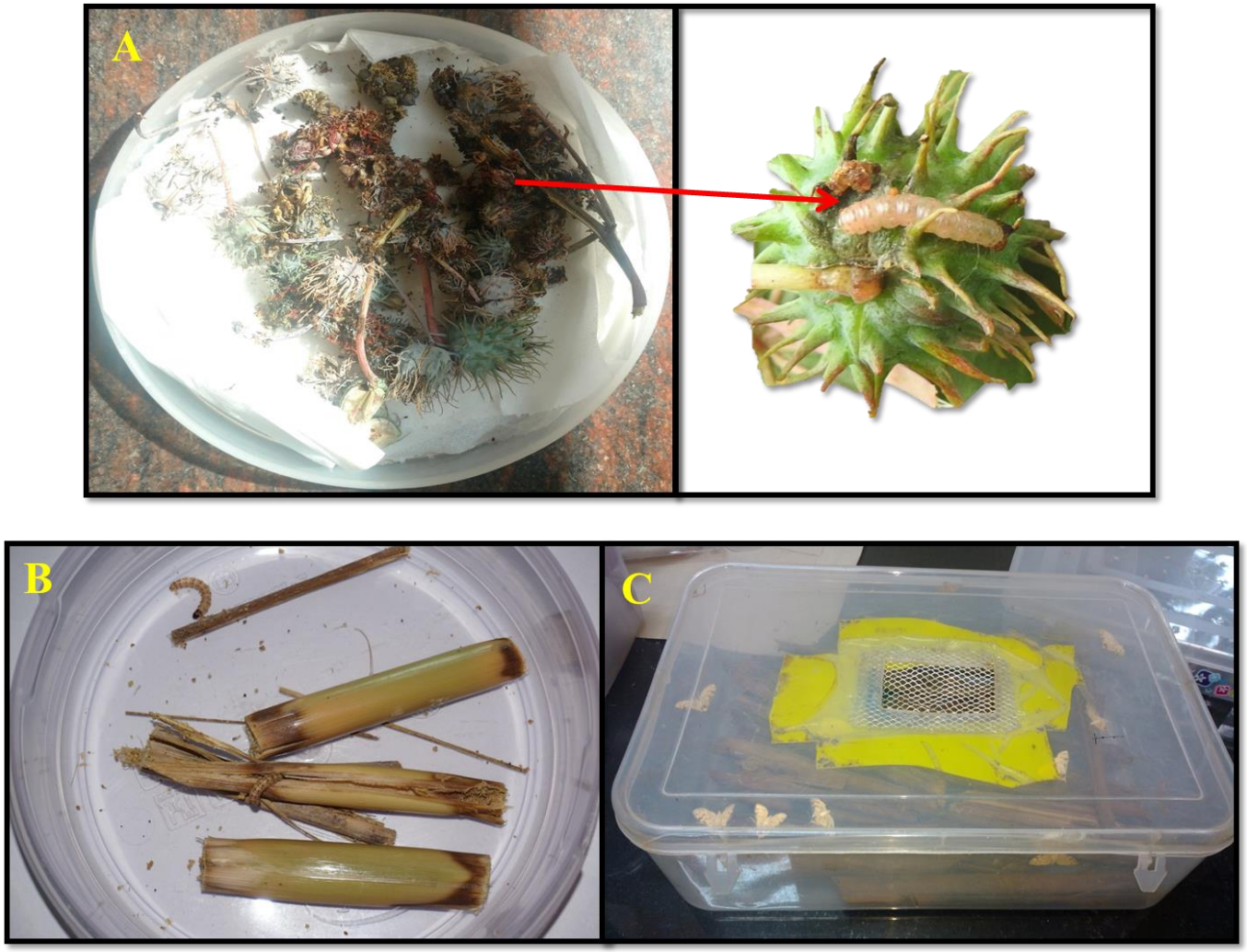

Plate 7. Natural food (diet D): A. Castor shoot and fruit borer reared on natural food (Castor capsules), B and C. Cardamom borer population reared on tender cardamom shoots.

Table 8. Composition of artificial diets (E_a-H_a) for rearing of *C. punctiferalis*

Parts	Ingredients	Artificial diets (g/ml)			
		Diet E_a	**Diet F_a**	**Diet G_a**	**Diet H_a (Control)**
A	Bengal gram powder (Commercially available)	100	100	100	100
	Castor capsule powder (Locally prepared)	**100**	**85**	**75**	**-**
	Yeast powder	25	20	25	25
	Casein	35	35	35	35
	Sucrose	15	15	15	15
	Distilled water	325	325	325	325
B	Agar-agar	15	15	15	15
	Distilled water	300	300	300	300
C	Ascorbic acid	3	3	3	3
	Wesson's salt mixture	1.5	1.5	1.5	1.5
	Sorbic acid	1	1	1	1
	Multivitamin, multimineral capsules	2	2	2	2
	Methyl parahydroxy benzoate	2	2	2	2
	Streptomycine sulphate	0.5	0.5	0.5	0.5
	Vit. E capsule USP 400mg	1	1	1	1
	Distilled water	75	75	75	75

Values show the quantities for 1000g artificial diet; Diets E_a-H_a are artificial diet and subscript letter indicated that diets are tested on C. punctiferalis.

Table 9. Composition of artificial diets (I_a-L_a) for rearing of *C. sahyadriensis*

Parts	Ingredients	Artificial diets (g/ml)			
		Diet I_a	**Diet J_a**	**Diet K_a**	**Diet L_a (Control)**
A	Bengal gram powder (Commercially available)	100	100	100	100
	Cardamom capsule powder (Locally prepared)	**100**	**85**	**75**	**-**
	Yeast powder	25	20	25	25
	Casein	35	35	35	35
	Sucrose	15	15	15	15
	Distilled water	325	325	325	325
B	Agar-agar	15	15	15	15
	Distilled water	300	300	300	300
C	Ascorbic acid	3	3	3	3
	Wesson's salt mixture	1.5	1.5	1.5	1.5
	Sorbic acid	1	1	1	1
	Multivitamin, multimineral capsules	2	2	2	2
	Methyl parahydroxy benzoate	2	2	2	2
	Streptomycine sulphate	0.5	0.5	0.5	0.5
	Vit. E capsule USP 400mg	1	1	1	1
	Distilled water	75	75	75	75

Values show the quantities for 1000g artificial diet; Diets I_a-L_a are artificial diet and subscript letter indicated that diets are tested on C. sahydriensis.

3.2b Effect of Casein on the development of *C. punctiferalis and C. sahyadriensis*

The variable quantities of casein were incorporated into the diets to study the effect on the growth and development of shoot and capsules borer. The details of diet combinations tested are presented in Tables 10 and 11.

Table 10. Composition of artificial diets (E_b-H_b) for rearing *C. punctiferalis*

Parts	Ingredients	Artificial diets (g/ml)			
		Diet E_b	**Diet F_b**	**Diet G_b**	**Diet H_b (Control)**
A	Bengal gram powder (Commercially available)	100	100	100	100
	Castor capsule powder (Locally prepared)	85	85	85	85
	Yeast powder	25	25	25	25
	Casein	**15**	**35**	**25**	**-**
	Sucrose	15	15	15	15
	Distilled water	325	325	325	325
B	Agar-agar	15	15	15	15
	Distilled water	300	300	300	300
C	Ascorbic acid	3	3	3	3
	Wesson's salt mixture	1.5	1.5	1.5	1.5
	Sorbic acid	1	1	1	1
	Multivitamin, multimineral capsules	2	2	2	2
	Methyl parahydroxy benzoate	2	2	2	2
	Streptomycin sulphate	0.5	0.5	0.5	0.5
	Vit. E capsule USP 400mg	1	1	1	1
	Distilled water	75	75	75	75

Values show the quantities for 1000g artificial diet; Diets E_b-H_b are artificial diet and subscript letter indicated that diets are tested on C. punctiferalis.

Table 11. Composition of artificial diets (I_b- L_b) for rearing *C. sahyadriensis*

Parts	Ingredients	Artificial diets (g/ml)			
		Diet I_b	**Diet J_b**	**Diet K_b**	**Diet L_b (Control)**
A	Bengal gram powder (Commercially available)	100	100	100	100
	Cardamom capsule powder (Locally prepared)	85	85	85	85
	Yeast powder	25	25	25	25
	Casein	**15**	**35**	**25**	**-**
	Sucrose	15	15	15	15
	Distilled water	325	325	325	325
B	Agar-agar	15	15	15	15
	Distilled water	300	300	300	300
C	Ascorbic acid	3	3	3	3
	Wesson's salt mixture	1.5	1.5	1.5	1.5
	Sorbic acid	1	1	1	1
	Multivitamin, multimineral capsules	2	2	2	2
	Methyl parahydroxy benzoate	2	2	2	2
	Streptomycin sulphate	0.5	0.5	0.5	0.5
	Vit. E capsule USP 400mg	1	1	1	1
	Distilled water	75	75	75	75

Values show the quantities for 1000g artificial diet; Diets I_b-L_b are artificial diet and subscript letter indicated that diets are tested on C. sahydriensis.

3.2c Effect of Vitamin E on fecundity of *C. punctiferalis and C. sahyadriensis* in artificial diets

To study the effect of Vitamin E on the fecundity of *C. punctiferalis and C. sahyadriensis* select quantities of Vitamin E were added into the diets. The details of diet combinations are presented in Tables 12 and 13.

Table 12. Composition of artificial diets (E_c-H_c) for rearing *C. punctiferalis*

Parts	Ingredients	Artificial diets (g/ml)			
		Diet E_c	**Diet F_c**	**Diet G_c**	**Diet H_c (Control)**
A	Bengal gram powder (Commercially available)	100	100	100	100
	Castor capsule powder (Locally prepared)	85	85	85	85
	Yeast powder	25	25	25	25
	Casein	35	35	35	35
	Sucrose	15	15	15	15
	Distilled water	325	325	325	325
B	Agar-agar	15	15	15	15
	Distilled water	300	300	300	300
C	Ascorbic acid	3	3	3	3
	Wesson's salt mixture	1.5	1.5	1.5	1.5
	Sorbic acid	1	1	1	1
	Multimineral capsules	2	2	2	2
	Methyl parahydroxy benzoate	2	2	2	2
	Streptomycin sulphate	0.5	0.5	0.5	0.5
	Vitamin E capsule 400 mg	**0.5**	**1**	**1.5**	**-**
	Distilled water	75	75	75	75

Values show the quantities for 1000g artificial diet; Diets E_c-H_c are artificial diet and subscript letter indicated that diets are tested on C. punctiferalis.

Table 13. Composition of different artificial diets (I_c-L_c) for rearing *C. sahyadriensis*

Parts	Ingredients	Artificial diets (g/ml)			
		Diet I_c	**Diet J_c**	**Diet K_c**	**Diet L_c (Control)**
A	Bengal gram powder (Commercially available)	100	100	100	100
	Cardamom capsule powder (Locally prepared)	85	85	85	85
	Yeast powder	25	25	25	25
	Casein	35	35	35	35
	Sucrose	15	15	15	15
	Distilled water	325	325	325	325
B	Agar-agar	15	15	15	15
	Distilled water	300	300	300	300
C	Ascorbic acid	3	3	3	3
	Wesson's salt mixture	1.5	1.5	1.5	1.5
	Sorbic acid	1	1	1	1
	Multimineral capsules	2	2	2	2
	Methyl parahydroxy benzoate	2	2	2	2
	Streptomycin sulphate	0.5	0.5	0.5	0.5
	Vitamin E capsule 400mg	**0.5**	**1**	**1.5**	**-**
	Distilled water	75	75	75	75

Values show the quantities for 1000g artificial diet; Diets I_c-L_c are artificial diet and subscript letter indicated that diets are tested on C. sahydriensis.

3.2d Effect of anti-microbial ingredients on growth and development of *C. punctiferalis* and *C. sahyadriensis* in artificial diets

Measured quantities of anti-microbial ingredients were incorporated into the diets to study their effect on the growth and development of *C. punctiferalis* and *C. sahyadriensis*. The details of diet combinations are as in Tables 14 and 15.

Table 14. Composition of different artificial diets (E_d-H_d) for rearing *C. punctiferalis*

Parts	Ingredients	Artificial diets (g/ml)			
		Diet E_d	**Diet F_d**	**Diet G_d**	**Diet H_d (Control)**
A	Bengal gram powder (Commercially available)	100	100	100	100
	Castor capsule powder (Locally prepared)	85	85	85	85
	Yeast powder	25	25	25	25
	Casein	35	35	35	35
	Sucrose	15	15	15	15
	Distilled water	325	325	325	325
B	Agar-agar	15	15	15	15
	Distilled water	300	300	300	300
C	Ascorbic acid	3	3	3	3
	Wesson's salt mixture	1.5	1.5	1.5	1.5
	Sorbic acid	**0.5**	**1**	**1.5**	**-**
	Multimineral capsules	2	2	2	2
	Methyl parahydroxy benzoate	**1**	**2**	**3**	**-**
	Streptomycin sulphate	**0.25**	**0.5**	**0.75**	**-**
	Vitamin E capsule 400 mg	1	1	1	1
	Distilled water	75	75	75	75

Values show the quantities for 1000g artificial diet; Diets E_d-H_d are artificial diet and subscript letter indicated that diets are tested on C. punctiferalis.

Table 15. Composition of different artificial diets (I_d-L_d) for rearing *C. sahyadriensis*

Parts	Ingredients	Artificial diets (g/ml)			
		Diet I_d	**Diet J_d**	**Diet K_d**	**Diet L_d (Control)**
A	Bengal gram powder (Commercially available)	100	100	100	100
	Cardamom capsule powder (Locally prepared)	85	85	85	85
	Yeast powder	25	25	25	25
	Casein	35	35	35	35
	Sucrose	15	15	15	15
	Distilled water	325	325	325	325
B	Agar-agar	15	15	15	15
	Distilled water	300	300	300	300
C	Ascorbic acid	3	3	3	3
	Wesson's salt mixture	1.5	1.5	1.5	1.5
	Sorbic acid	**0.5**	**1**	**1.5**	**-**
	Multimineral capsules	2	2	2	2
	Methyl parahydroxy benzoate	**1**	**2**	**3**	**-**
	Streptomycin sulphate	**0.25**	**0.5**	**0.75**	**-**
	Vitamin E capsule 400mg	0.5	1	1.5	-
	Distilled water	75	75	75	75

Values show the quantities for 1000g artificial diet; Diets I_d-L_d are artificial diet and subscript letter indicated that diets are tested on C. sahydriensis.

3.2.4 Mass rearing *C. punctiferalis* and *C. sahyadriensis*

The water drops formed due to moisture along the inner side of rearing vials containing the diet were dried with sterilized soft tissue paper. A fine hole was made on the upper surface of the diet in the vials with the help of sterilized knife to allow the freely hatched larvae to enter the diet easily. To compare formulated artificial diets A, B and C with the diet D, 30 neonate *C. punctiferalis and C. sahyadriensis* larvae obtained from stock culture were transferred into each screw capped plastic vial (5 x 4 cm) using a fine hair brush. The vials were covered with a transparent plastic lid with small holes for ventilation. From the 2^{nd} to 5^{th} generations, the *Conogethes* population was solely reared on the artificial diets. Larval survival and development were recorded daily. When the larvae reached penultimate stage, the cotton cloth (100 x 75mm) was placed on to the diet blocks to provide pupation sites. The freshly formed pupae were collected from rearing vials, sexed, numbered, weighed and placed in plastic boxes (15 x 6 cm) for adult emergence. Pupal survival, duration and adult emergence were recorded daily. Each treatment was replicated five times with a total of 150 larvae/diet treatment/generation.

For each diet treatment, newly emerged *C. punctiferalis* and *C. sahyadriensis* adults (Plate 9) (1:1; female: male) were paired and released into the ventilated glass cages (60 x 60 x 60 cm) containing castor inflorescence (raceme), cardamom or ginger plants for respective diets (Plate 8B). The panicle and young capsules were placed in 500 ml conical flask with water to mimic natural ambience and fed with 10 per cent honey solution soaked in cotton swabs/wads and provided with black cloth (Plate 8A) for mating and oviposition. Eggs deposited on plant parts, cotton swabs and black cloth (Plate 9) were collected and counted. Adult longevity was also recorded. Eggs were counted under a microscope (Nikon SMZ25, 1x, WD: 60) (Plate 10) and placed into the petri dishes (8cm). The number of hatched F_1 larvae was counted daily. Castor panicle with flowers and young capsules (Plate 8A), and cardamom shoots were used as a control diet (diet D). Rearing conditions and experimental procedures were the same as that of the artificial diet treatments.

3.2.5 Observations

The response of the shoot and capsule borer to different artificial diets (Diet A, B, C, E, F, G, H, I, K and L) and natural diet D was assessed by recording the following biological attributes:

3.2.5.1 Egg period and viability

Freshly laid eggs were transferred into petridishes (10cm dia.) containing young capsule and shoots of castor and cardamom, respectively as a food for newly hatched larvae for growth and development in next the generation cycle. A set of 35 eggs were taken to study the insect biology on the test artificial diet. Measurements on length and breadth of eggs were recorded with the help of ocular scale after calibrating with stage micrometer. Time taken for hatching was recorded to compute the incubation period. The eggs which could not hatch were counted and from this the number of viable eggs was worked out. The hatched larvae in second generation cycle were observed daily and data were recorded.

3.2.5.2 Larval period

The numbers of freshly hatched larvae released into the diet were observed daily to record the survival. The number of larvae metamorphorised into pupae was recorded daily. Pupae of *Conogethes* were taken out/removed from the diet vials and placed separately in plastic boxes (15 x 6cm) provided with moist rubber sponge at bottom. The average larval period was worked out from the date of release of freshly hatched larvae until pupation in the test diet.

3.2.5.3 Pupal period

The pupae formed from first ten larvae as mentioned in step **3.1.5.2** were observed daily for the emergence of adults. The pupal period was calculated from the date of pupation to the date of emergence of moths.

3.2.5.4 Pupal weight

Ten pupae of *Conogethes* were maintained separately in plastic tube (15 x 6 cm) kept for studying the pupal period. For calculating average pupal weight, five matured

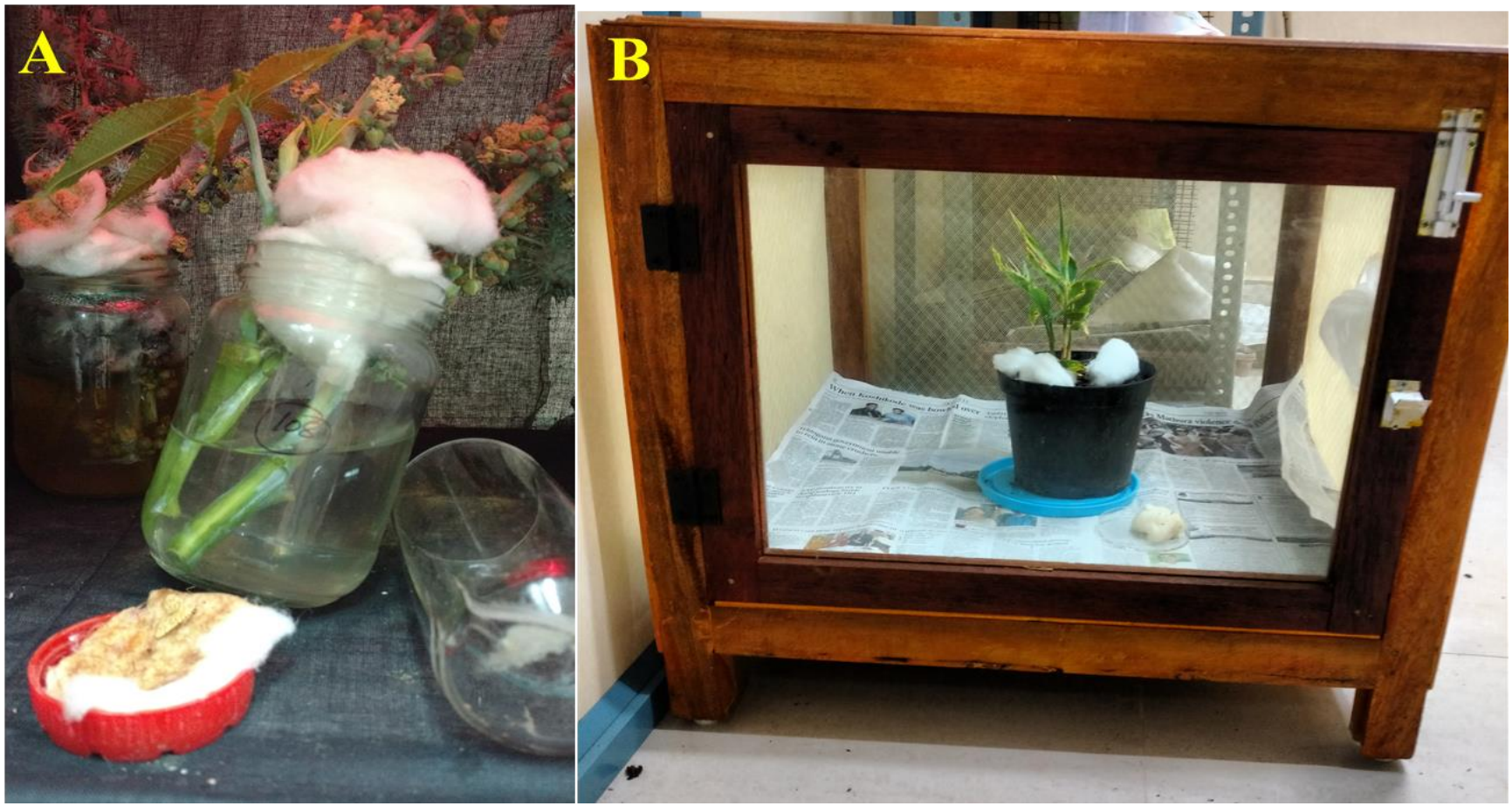

Plate 8. Ovipositional cage of shoot and fruit borer: A. Castor plant parts, cotton swabs, black cloth; B. Ovipositional cage with ginger plant pot and cotton swabs

Conogethes pupae were randomly taken from each replication of the diet. The weight of each pupa was recorded, and it was kept in plastic tube (15 x 6 cm) till adult emergence. The average weight of pupa (male and female) was calculated by dividing total weight of pupae with actual number of pupae of that particular sex.

3.2.5.5 Pupation (%)

The per cent pupation was worked out from the number of pupae formed by the total number of larvae released into the diet.

$$\text{Pupation (\%)} = \frac{\text{Number of pupae formed}}{\text{Total number of larvae released}} \times 100$$

3.2.5.6 Sex differences in pupal stage

For determining the sex differences at the pupal stage, observations were recorded on abdominal segment of the pupae under a microscope (Nikon SMZ25, 1x, WD: 60) (Plate 10). In case of female, the distance between genital slit and last abdominal segment was less compared to male pupae where the distance between genital slit and last abdominal segment was more (Plate 11). Ten pupae were examined for each sex.

3.2.5.7 Adult emergence (%)

The pupae as mentioned in **3.1.5.3** were observed daily for adult moth emergence and the number of adults emerged was recorded. The total number of moths emerged was recorded. The percentage of moth emergence was worked out on the basis of number of moths emerged by the total number of larvae matured or pupae in the diet.

$$\text{Emergence (\%)} = \frac{\text{Number of moths emerged}}{\text{Total number of pupae}} \times 100$$

3.2.5.8 Sex ratio

The sex ratio was determined by the formula based on sexual dimorphism in the pupa, as described by Butt and Cantu (1962).

$$\text{Sex ratio} = \frac{\text{No. of females}}{\text{No. of females + No. of males}} \times 100$$

3.2.5.9 Pre-oviposition

Male and female moths were allowed to mate and then transferred them to rearing cages ($0.3m^3$). After the adult emergence, observations were recorded once in six hours. The time taken for egg laying was considered as the pre- oviposition period.

3.2.5.10 Fecundity

Conogethes sp. moths emerging from the vials of a single diet on one day were taken for pairing. Five pairs of moths were put into one oviposition cage (60 x 60 x 60 cm) for egg laying. Eggs deposited on plant parts, cotton swabs and black cloth in the ovipositon cage (60 x 60 x 60 cm) were collected and counted under a microscope (Nikon SMZ25, 1x, WD: 60) (Plate 10) and placed in petri dishes (8cm dia.), and then average fecundity of a female was worked out.

3.2.5.11 Post-ovipositional period

The time after the oviposition till the moths ceased laying eggs was considered as post-ovipositional period. The adults were reared in each case. Based on the time consumed, duration of the post-ovipositional period was computed.

3.2.5.12 Adult longevity

The adults of *Conogethes* emerged (Plate 8) from the respective artificial diets on one day were kept separately in cages and observed daily to record mortality/survival. Four moths of either sex were observed for the longevity from each diet vial. The period elapsed between the date of emergence to death was taken as adult longevity.

3.2.5.13 Growth index

It was worked out from the per cent survival of full grown larvae by the duration of larval period.

Plate 9. Adult moths on black cloth for oviposition: A. Castor shoot and capsule borer, C. *punctiferalis,* B. Cardamom borer, C. *sahyadriensis*

Plate 10. Microscope used for eggs count and sex identification in pupal stage

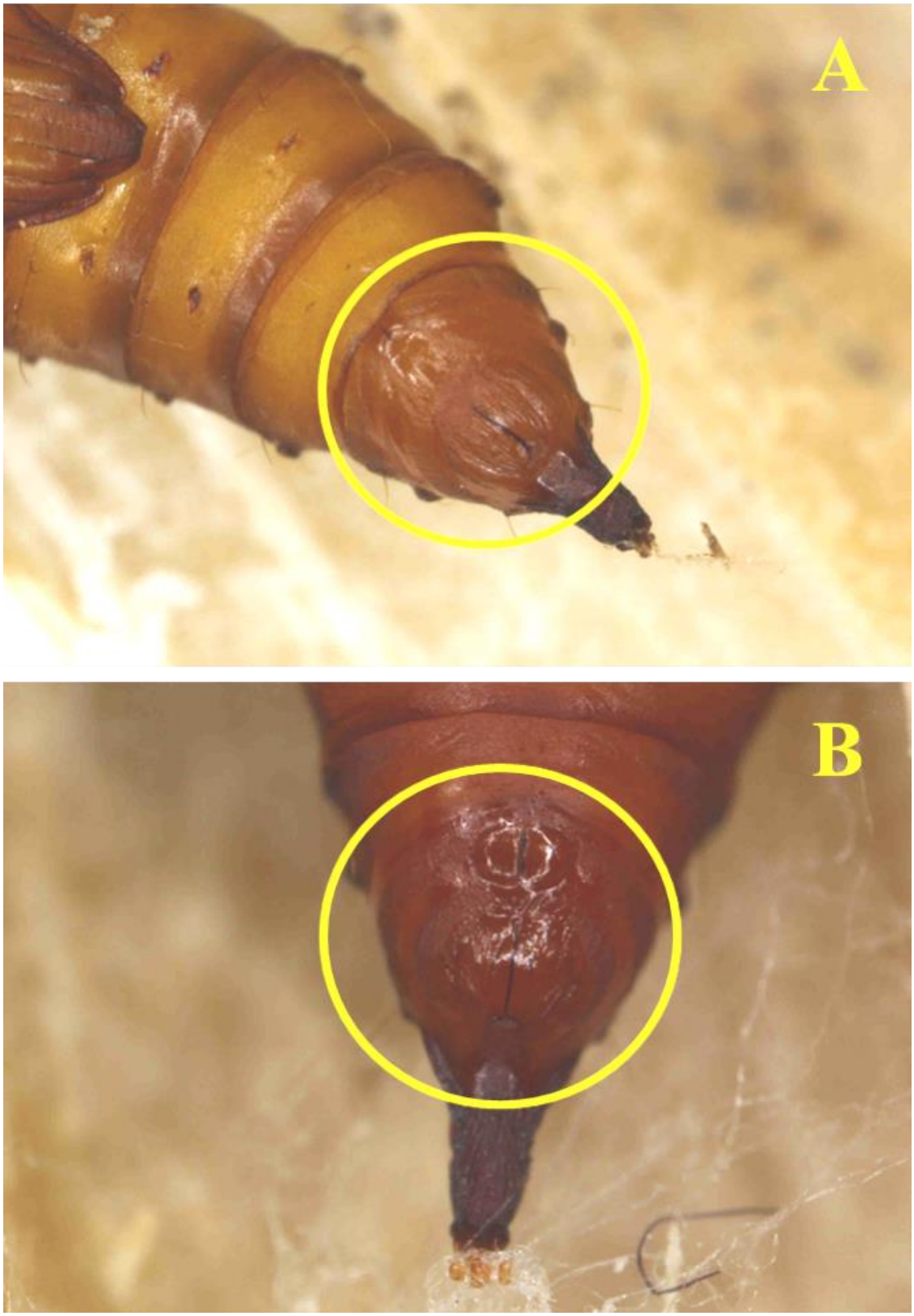

Plate 11. Sex differentiation in pupal stage of shoot and capsule borer: A. Male pupa, B. female pupa

$$\text{Growth Index} = \frac{\text{Per cent survival of full grown larvae}}{\text{Duration of larval period (days)}} \times 100$$

The total developmental period was calculated as the sum total by adding incubation period, larval period and pupal period. Number of replications taken for studying all the above mentioned parameters was six for each diet. For fecundity, 5 pairs of moths per replicate were taken for each artificial diet.

3.2.6 Economics of diet

It was evaluated by summing up the cost of ingredients used for preparation of diet.

3.2.7 Temperature and relative humidity

Stock culture of *Conogethes* sp. was maintained in the laboratory under controlled temperatures of 24-28ºC and relative humidity ranging from 70 to 80 per cent. However, the pupal stage required more moisture as compared to other developmental stages. So the plastic box (15 x 6cm) having pupae were provided with moistened rubber sponge for additional humidity. For eggs, moistened cotton pads were kept in the surroundings of the petridish (10 x 1.5cm) to maintain required humidity. Temperature was recorded with a thermometer and relative humidity with a dry and wet bulb thermometer daily at 8 a.m., 12 p.m. and 4 p.m., for the study period.

3.2.8 Biometric analysis

The data obtained on different parameters of the biology of shoot and capsule borer, *C. punctiferalis* and *C. sahyadriensis* reared on different artificial diets and natural food across four generations were subjected to statistical analysis using Analysis of Variance and the Bonferroni test with SPSS 23.0 statistical software.

3.2.9 Life table parameters

- **Intrinsic Rate of Increase/Innate Capacity of Increase in numbers, (r)** (no. of female off-springs/female/day) is the maximal rate of increase by the combination

of food, temperature, quality of food, *etc*. Intrinsic Rate of Natural Increase was computed using the formula

$$r = \frac{\log_e R_0}{T} \text{ X } 100 \quad \text{or} \quad r = \ln(\lambda)$$

Where,

T = Mean Generation Time (days)

R_o=Net Reproduction Rate (no. of new born females/female/generation)

r= Intrinsic Rate of Increase (no. of female off-springs/female/day)

ln = Natural log

λ = Finite Rate of Increase in number

- **The Finite Rate of Increase in number (λ)** was calculated using the formula,

$$\lambda = \text{anti ln} \quad \frac{\log_e R_0}{T}$$

Where, R_o and T are specifically defined

- **The Net Reproductive Rate, (R_o) (no. of female off-springs/female/ generation)** is the average number of new born females produced female moth during entire life time. It is the sum of the products of lx and mx.

$$R_o = \Sigma \, lxmx$$

Where,

lx = proportion of females alive in age interval (x),

lxmx = the number of female off-springs per original female produced in age interval (x)

- **The mean generation time, T (days)** was defined as the time required for a population to increase to R_0-fold of its population size at the stable stage distribution or the average age of parenthood, was calculated using the formula

$$T = (\ln R_0)/r$$

- **The Gross reproductive rate (GRR)** was computed as

$$GRR = \Sigma mx$$

Where,

mx = the number of female off-spring produced per surviving female in the age interval (x)

Finally, the means, standard errors and variances of life table parameters were estimated via the bootstrap technique (Efron and Tibshirani, 1993), which is contained in the TWOSEX-MS Chart program. The computer program, TWOSEX-MS Chart, for the age-stage two-sex life table analysis in Visual BASIC (version 6, service pack 6) for the Windows system, available on http://140.120.197.173/Ecology/Download/TWOSEX-MSChart.rar (National Chung Hsing University, Taiwan) and on http://nhsbig.inhs.uiuc.edu/wes/chi.html (Illinois Natural History Survey, USA) was used for analysis of life table data.

3.3 Field evaluation of identified pheromone components of *C. punctiferalis* on Castor and Cardamom

The materials used and methods employed for conducting different experiments on shoot and fruit borer moth, *C. punctiferalis* in the local farmers-castor and cardamom infested fields are presented here. The aspects studied are longevity/release rate of pheromones in the field exposed lures, trap type, colour, height and numbers to be used, effect of trapping male moths on population reduction, large scale field testing of the mass trapping technology in castor fields (Plate 12) in and around Pavagada, Tumkur and Hiryur, Chitradurga; in cardamom fields in and around Mudigere, Chikmangalur (Plate 13) are presented here under.

3.3.1 Pheromone Sample

The composition of the pheromone components of *Conogethes punctiferalis* are (*E*)-10-hexadecenal (E10-16:Ald), (*Z*)-10-hexadecenal (Z10-16:Ald) and hexadecenal (16:Ald) at 100:8:16 (3 mg/septa). The pheromone impregnated rubber septa used in these studies were manufactured and supplied by Division of Bio-control Research Laboratories,

M/s Pest Control (India) Ltd. Bombay, Sreeramanahalli, Arakere post, Bengaluru, Karnataka, South India.

3.3.2 Evaluation of traps

Evaluation of trap designs on moth catches were conducted in the borer infested castor fields (Plate 12), Pavagada, Tumkur (14.1°N, 77.27°E with 646m MSL) and cardamom fields at local farmer field (Plate 13), Mudigere, Chikmangalur, Karnataka (12°25'N; 75°43'E and 980 mt MSL). The cross-vane traps, delta traps, water traps and funnel traps were selected for screening (Table 16; Plate 14). The pheromone impregnated rubber septa were suspended at the middle in water traps using lure holder. Three fourths of the water traps were filled with water. About 5ml of castor oil was poured onto the surface of water. The purpose of using the oil was to retain the trapped moths. Each trap type was replicated 4 times and the traps were installed at crop canopy level. Traps were placed at randomly chosen locations about 10m apart in castor and cardamom fields at the test locations. Traps without pheromone lures were used as control.

Observations were made on larval infestation before traps installation and total number of moths trapped at weekly intervals. Old and new larval infestations were distinguished to detect fresh infestations after trapping the moths, if any. Most attractive trap type was selected based on number of moth catches in the traps to evaluate other factors such as trap color and height. The experiment was laid out following randomized complete block design. Trap data were subjected to two-way Analysis of Variance (ANOVA) following RCBD. The details of the field layout and treatments are described in Tables 16 and 17, respectively.

Plate 12. Infested castor field for pheromone traps studies against *C. punctiferalis*; A. Infested field, B. Nature of damage

Plate 13. Pheromone traps installed infested cardamom field against *C. sahyadriensis*; A. Delta trap, B. Water trap

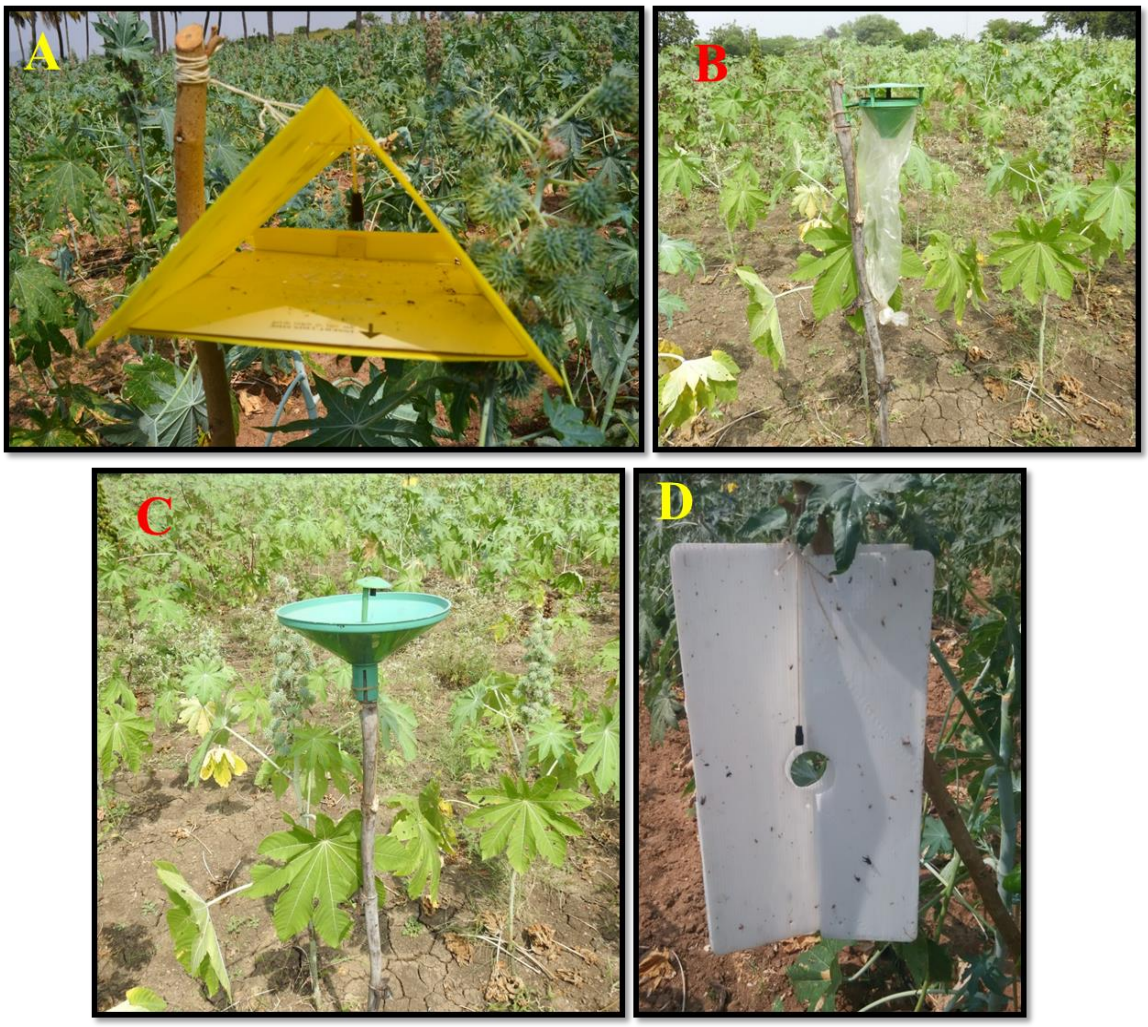

Plate 14. Different pheromone traps installed in castor field: A. Delta trap, B. Funnel trap, C. Water trap D. Cross vane trap

Table 16. The treatments for evaluation of traps

Treatments	Details
T_1	Delta trap with lure
T_2	Delta trap without lure
T_3	Cross vane trap with lure
T_4	Cross vane trap without lure
T_5	Funnel trap with lure
T_6	Funnel trap without lure
T_7	Water trap with lure
T_8	Water trap without lure

Table 17. The field layout of the treatments in the field experiment

T_2R_1	T_1R_2	T_4R_3	T_3R_4
T_4R_1	T_3R_2	T_6R_3	T_2R_4
T_7R_1	T_5R_2	T_1R_3	T_8R_4
T_6R_1	T_8R_2	T_5R_3	T_7R_4
T_8R_2	T_2R_2	T_7R_3	T_6R_4
T_1R_2	T_6R_2	T_3R_3	T_5R_4
T_3R_2	T_4R_2	T_8R_3	T_1R_4
T_5R_2	T_7R_2	T_2R_3	T_4R_4

3.4 Sex pheromone trapping plan

Pheromone traps and lures were obtained from Bio-Control Research Laboratory (BCRL), Sriramanahalli, Bengaluru for standardization of trap design under field conditions. The studies were conducted considering the following factors.

3.4.1 Trap colour

Delta traps of four different colours *viz*., red, green, yellow and white were chosen and installed with four replications each in the *C. punctiferalis* infested field at crop canopy

level (Plate 15). Traps without pheromone lures were used as control and replicated four times. Eight treatments (traps with lure and without lure) were replicated four times in the study. Observations on moth catches were recorded at weekly intervals and the data were subjected to two-way analysis of variance (ANOVA). The details of the treatments and the layout are described in Tables 18, 19 and 20, respectively.

Table 18. The treatments for trap colours

Treatments	Details
T_1	Yellow with lure
T_2	Yellow without lure
T_3	Green with lure
T_4	Green without lure
T_5	Red with lure
T_6	Red without lure
T_7	White with lure
T_8	White without lure

3.3.2 Effect of trap height on moth catches

For this experiment, selected traps baited with pheromones were set up using required lengths of wooden pegs. Eucalyptus/bamboo pegs were used as these are straight and are firm enough to hold the traps. The treatments were replicated 5 times. The traps baited with pheromone lures were placed at randomly chosen locations about 10 m apart in castor fields at the test location. The observations on the moth catches in traps were made at weekly intervals. Later, detailed observations were made on per cent larval reduction and moth catches in the traps over a period. The data were transformed to $\sqrt{X + 0.5}$ before analysis by Two way ANOVA following RCBD. The details of the treatments and the field layout are as follows (Tables 19 and 20, respectively).

Plate 15. Different coloured delta traps installed in castor field: A. white delta trap, B. red delta trap, C. Green delta trap and D. yellow delta trap.

Table 19. The treatments for trap heights

Treatments	Details
T_1	0.3m above the crop canopy
T_2	0.1m above the crop canopy level
T_3	Equal to crop canopy level
T_4	0.3m below the crop canopy level

Table 20. The field layout of the treatments in the field experiment

T_4R_1	T_4R_2	T_3R_3	T_4R_4	T_3R_5
T_2R_1	T_1R_2	T_4R_3	T_3R_4	T_3R_5
T_3R_1	T_3R_2	T_2R_3	T_1R_4	T_1R_5
T_4R_1	T_2R_2	T_1R_3	T_2R_4	T_2R_5

3.3.3 Release rate of pheromone components

To calculate the field viability of the lures to attract male moths, or to understand the release/dissipation rate of the pheromones were evaluated with pheromone lures that were exposed in field at different lengths of time. Pheromone septa were loaded with 3mg of synthetic pheromone at Bio-Control Research Laboratory (BCRL), Sriramanahalli, Bengaluru. Pheromone lures were placed in delta traps installed in *C. punctiferalis* infested castor field at ZAHRS, Babbur farm, Hiryur, Chitradurga (Dist.) during 2016-17. The field installed pheromone lures were regularly brought to the laboratory at 0, 15, 30, 45 and 60 days after installation and the quantity of pheromone remaining in the black rubber septa were assessed using gas chromatography procedures.

Extraction of pheromone from the lures

The field collected lures (10 in numbers) were brought to the laboratory and immersed in a 20 ml sample vial containing hexane as a solvent and known quantity of internal standard (0.2 mg/ ml of 1 tetradecanyl acetate (14:Ac)) was added. The samples were maintained in a freezer until the time for Gas chromatography analysis of the residual pheromone to avoid future decomposition. The quantity of pheromone component present

in the sample was calculated by comparing with the quantity of chemical present in the internal standard.

3.3.4 Gas Chromatography

The lure extracts were tested and compared with standard synthetic pheromone compound viz., (*E*)-10-hexadecenal (E10-16:Ald), (*Z*)-10-hexadecenal (Z10-16:Ald) and hexadecenal (16:Ald) at 100:8:16 (3 mg/septa). The contents of lure extracts and standard compounds were analyzed using Agilent 7890AGC system equipped with HP-5 column (30 m x 0.25 mm i.d, 0.25μmfilm). N2 at the flow rate of 1.2 ml min-1was used as the carrier gas. The injector was kept at 225ºC and the detector at 300ºC, the column oven was kept in a temperature programme of 60ºC with a hold time of 2 min, then raised up to 220ºC at a rate of 10ºC min-1 with a hold time of 60 min. The GC was fitted with the Flame Ionisation Detector (FID). The split injector with the ratio of 10:1 was used (Plate 16).

Gas chromatography analysis of residual pheromone

The study was performed with an Agilent 6890 model as explained earlier. The gas chromatographic data were collected and processed using AGILENT 7890AGC system. The release rate was calculated by comparing standard dosage and expressed as per cent released over time and regression analysis was performed to best fit the relationship between the amounts released over time.

Plate 16. Gas Chromatograph

IV RESULTS AND DISCUSSION

As the studies on the borer were initiated on castor and cardamom, the species was considered as *Conogethes punctiferalis* on both the plants. As the studies progressed, only in the early 2018 it was clearly and comprehensively established that the borer on castor is *Conogethes punctiferalis* (Guenée) and on cardamom *Conogethes sahyadriensis* Shashank *et al*. (2018). Results of the current experiments conducted from 2016-18 also supported the fact that the two *Conogethes* species on castor and cardamom are distinctly different. *C. sahyadriensis* is a sister-species of *Conogethes pluto* and *C. punctiferalis* is one of the component species of *C. punctiferalis* complex. It's with this background that studies on *Conogethes* were conducted and concluded.

The results and discussion of the present experiments conducted to study on mass rearing of shoot and capsule borers, *C. punctiferalis* and *C. sahyadriensis* was studied during 2016-17 under laboratory conditions at the Division of Entomology and Nematology, ICAR-Indian Institute of Horticultural Research (IIHR), Hessaraghatta, Bengaluru and seasonal incidence of *C. punctiferalis* on castor were conducted at Gangasagar, Pavagada, Tumkur; Babbur farm, Hiryur, Chitradurga and Dryland Research Station, UAS, GKVK, Bengaluru. Studies on *C. sahyadriensis* on cardamom were conducted at Mr Satish cardamom estate and at Zonal Agricultural and Horticultural Research Station (ZAHRS), Mudigere. Studies on ginger plants at local farmer estates of Hassan, Shivamogga and Kodagu districts during 2015-17. Investigations were also made on field evaluation of pheromone components of *C. punctiferalis* during 2016-17 in castor fields in and around Pavagada, Tumkur; Hiryur, Chitradurga and Dryland Research Station, UAS, GKVK, Bengaluru; in cardamom plantations in and around Mudigere, Chikkamagalur. The discussions on the results of the investigations are also included in this chapter embracing all the aspects of the study.

4.1 Seasonal incidence of *C. punctiferalis* and *C. sahyadriensis*

For developing pest avoidance techniques and knowing the availability of insects in sufficient number under natural conditions on natural host plant for both species of *Conogethes*, the basic requirement is the availability of data on pest seasonal incidence. In

view of the above, the present studies on seasonal incidence of *C. punctiferalis* and *C. sahyadriensis* were undertaken.

4.1.1 Seasonal incidence of the cardamom borer, *C. sahyadriensis*

Seasonal incidence of the cardamom borer, *C. sahyadriensis* is presented in Table 21. Seasonal incidence of the borer was recorded at two cardamom plantations at Mudigere, Chikmangalur from January 2016 to December 2017 at fortnight intervals. The borer infestation was recorded on shoots and capsules. Maximum infestation of the borer was recorded on shoots during May and capsules during October-November in 2016. Similar trend in infestation of shoot and capsule borer was recorded during 2017.

At both the plantations, the per cent infestation on shoots varied from 5 to 25 and on capsules from nil to 15% in 2016 (Fig. 1). The corresponding figures for 2017 were 3 to 28 per cent on shoots and on capsules from nil to 15 per cent (Table 21 and Fig. 3). This data suggested that the borer infestations on cardamom shoots persisted throughout the year and on capsules from May to December at both cardamom plantations. It also suggested that the cardamom borer, *C. sahyadriensis* is an economically important pest on cardamom and management practices is required on cardamom plantations from borer damage.

4.1.1a Correlation between incidence of *C. sahyadreinsis* and abiotic factors

In order to pinpoint the factors influencing borer infestation on cardamom correlation and regression analysis were run. The analyses of ZAHRS, Mudigere, 2016 observations revealed that maximum temperature (r =-0.572 on capsule) had negative impact on borer infestations, while minimum temperature (r=0.578 on shoot), relative humidity during morning hours (r=0.669 on capsule) and evening hours *(*r=0.645 on capsule) had positive correlation with borer infestation. Whereas, in Satish farm, Mudigere, 2016 revealed that maximum temperature (r =-0.580 on capsule), sunshine hours (r =-0.478 on capsule) and relative humidity during morning hours (r= -0.520 on shoot) had significantly negative correlation with *C. sahyadreinsis* borer infestation, while minimum temperature (r=0.555 on shoot), relative humidity during morning hours

Table 21. Seasonal incidence of borer, *C. sahyadriensis* on cardamom, 2016 and 2017

Month	Fortnight	Mean % infestation, 2016				Mean % infestation, 2017			
		ZAHRS, Mudigere		Satish Farm, Mudigere		ZAHRS, Mudigere		Satish Farm, Mudigere	
		Shoot	Capsule	Shoot	Capsule	Shoot	Capsule	Shoot	Capsule
January	I	6.93	0.00	5.77	0.00	15.03	0.00	13.25	0.00
	II	7.95	0.00	8.21	0.00	7.97	0.00	6.49	0.00
February	I	6.16	0.00	7.65	0.00	5.14	0.00	5.27	0.00
	II	5.03	0.00	6.21	0.00	4.06	0.00	3.31	0.00
March	I	7.18	0.00	8.17	0.00	6.07	0.00	4.28	0.00
	II	8.42	0.00	10.44	0.00	10.30	0.00	7.74	0.00
April	I	15.45	0.00	16.38	0.00	15.13	0.00	16.78	0.00
	II	17.00	0.00	18.57	0.00	15.87	0.00	18.86	0.00
May	I	**21.92**	2.13	**23.31**	1.95	**24.95**	1.00	**28.37**	0.00
	II	**25.05**	2.65	**27.73**	2.50	**26.13**	1.85	**26.95**	1.50
June	I	**19.10**	3.75	**22.11**	3.25	**20.58**	3.50	**25.12**	4.25
	II	15.24	4.55	18.86	5.05	16.50	5.65	15.30	5.75
July	I	16.55	5.60	14.41	5.50	13.12	6.25	14.26	6.00
	II	12.35	6.70	11.31	6.45	12.11	6.45	10.01	6.50
August	I	11.72	10.05	12.07	9.85	10.84	9.85	11.04	9.95
	II	8.70	11.35	7.59	11.30	6.63	11.30	5.89	11.70
September	I	6.33	12.00	5.84	11.90	4.15	11.90	4.91	12.18
	II	5.03	**14.10**	4.16	13.75	6.67	13.50	2.48	**13.25**
October	I	9.20	**14.25**	6.59	**14.00**	8.12	**13.85**	10.80	**14.50**
	II	10.36	**14.00**	11.55	**14.20**	9.34	**14.20**	13.73	**14.65**
November	I	12.58	**14.95**	13.18	**14.75**	14.56	**13.75**	16.07	10.50
	II	14.20	5.70	15.12	4.95	17.54	4.50	18.63	5.75
December	I	16.13	0.00	19.20	1.10	19.57	1.50	20.10	1.16
	II	20.14	0.00	21.02	0.00	21.88	0.00	22.06	0.00

n= 15 clumps/plot/15days

(*r*=0.658 on capsule) and evening hours *(r*=0.650 on capsule) had significant and positive effect on *C. sahyadriensis* infestations both on shoots and capsules (Table 22 and Fig. 2).

The analyses of ZAHRS, Mudigere, 2017 observations revealed that maximum temperature (*r* =-0.558 on capsule), minimum temperature (*r* =-0.486 on shoot) and sunshine hours (*r* =-0.583 on capsule) had negative impact on borer infestations, while maximum temperature (*r*=0.516 on shoot), relative humidity during morning hours (*r*=0.475 on capsule) and evening hours *(r*=0.445 on capsule) had positive correlation with borer infestation. Whereas, in Satish farm, Mudigere. 2017 revealed that maximum temperature (*r* =-0.583 on capsule), minimum temperature (*r* =-0.546 on shoot), relative humidity during morning hours (*r*=-0.518 on shoot) and sunshine hours (*r* =-0.612 on capsule) had negative impact on *C. sahyadreinsis* borer infestation, while relative humidity during morning hours (*r*=0.470 on capsule) and evening hours *(r*=0.447 on capsule) had significant and positive effect on *C. sahyadriensis* infestations both on shoots and capsules (Table 23 and Fig. 4). Thus, weather parameters like temperature and relative humidity significantly influenced borer infestations on cardamom. It can be inferred from this data that regulation of shade can bring about changes in micro-habitat conditions which in turn effect borer infestations.

Shoot and fruit borer, *C. sahyadreinsis* occurred throughout the year on Cardamom in Western Ghats in South India. Two peaks in the borer population were noticed in a year, i.e. one during April - May and the other during November – December (Thyagaraj, 2003). The population coincided with the period of less or no rainfall, i.e. during pre and post-monsoon periods (Ballard, 1927; Ono, 1937; Thyagaraj, 2003). The population of borer, *C. sahyadreinsis* was recorded in the field throughout the year on cardamom but is reported to be higher during January–February, May and September–October at Idukki (Kerala) (Varadarasan *et al.,* 1989) and during January, March, June, August and October at Thadiyankudisai (Varadarasan *et al.,* 1991). At Mudigere (Karnataka), it was reported to peak during September-October on the cardamom tillers (Krishnamurthy *et al.,* 1989).

4.1.1b Regression between incidence of *C. sahyadreinsis* and abiotic factors

Further studies on this relationship are desirable. To eventually confirm the role of weather parameters in influencing borer damage on cardamom, regression analyses were affected on the relevant data (Table 23). Again, the borer infestations were recorded from two cardamom plantations. It was found that the maximum temperature and relative humidity during morning hours had positive and significant impact on borer damage, respectively. At Satish cardamom plantation also, maximum temperature had negative impact on borer damage and relative humidity during morning hours had significant and positive impact on borer infestations on cardamom capsules. In effect, the data confirmed that temperature and relative humidity in cardamom plantations are crucially important to regulate borer populations. The multiple regression equation fitted with *C. sahyadreinsis* and weather parameter of the ZAHRS and Satish farm, Mudigere. 2016-2017 to predict the cardamom shoot and capsule borer percent infestation (Y) was

ZAHRS, Mudigere, 2016

Shoot*:* *N*=24, $\boldsymbol{R^2}$**= 0.363**, Y_1 (Per cent infestation on shoot) = 55.722 + 0.480(X_1) + 1.106(X_2) - 1.252(X_3) - 1.776(X_4) + 1.252(X_5) + 0.559(X_6)

Capsules: *N*=24, $\boldsymbol{R^2}$**= 0.708**, Y_2 (Per cent infestation on Capsules) = -179.741 -0.207(X_1) -1.569(X_2) + 0.057(X_3) + 2.388(X_4) + 0.300(X_5) + 1.125(X_6)

Satish farm, Mudigere, 2016

Shoot*:* *N*=24, $\boldsymbol{R^2}$**= 0.315**, Y_3 (Per cent infestation on shoot) = 54.101 + 0.490(X_1) + 1.248(X_2) - 1.232(X_3) - 1.851(X_4) + 1.300(X_5) + 0.638(X_6)

Capsules: *N*=24, $\boldsymbol{R^2}$**= 0.713**, Y_4 (Per cent infestation on Capsules) = -170.451 - 0.189(X_1) -1.612(X_2) + 0.072(X_3) + 2.231(X_4) + 0.357(X_5) + 1.200(X_6)

ZAHRS, Mudigere, 2017

Shoot*:* *N*=24, $\boldsymbol{R^2}$**= 0**.483, Y_1 (Per cent infestation on shoot) = -27.768 + 1.660(X_1) - 5.638(X_2) + 2.062(X_3) - 0.821(X_4) + 0.124(X_5) - 1.243(X_6)

Capsules: *N*=24, $\boldsymbol{R^2}$**= 0.463**, Y_2 (Per cent infestation on Capsules) = -47.620 -0.698(X_1) + 1.973(X_2) + 0.363(X_3) + 0.088(X_4) - 0.313(X_5) - 0.662(X_6)

Table 22. Correlation between weather parameters and the shoot and capsule borer on cardamom, 2016

Weather Parameters	Correlation coefficient (*r*)			
	ZAHRS, Mudigere		Satish farm, Mudigere	
	Shoot	Capsule	Shoot	Capsule
X_1 - Rainfall (mm)	0.280 NS	0.170 NS	0.196 NS	0.173 NS
X_2 - Maximum temperature (^{0}C)	0.154 NS	-0.572**	0.222 NS	-0.580**
X_3 - Minimum temperature (^{0}C)	0.578**	-0.287 NS	0.555*	-0.292 NS
X_4 - Relative humidity morning (%)	0.031 NS	0.669**	-0.520*	0.658**
X_5 - Relative humidity evening (%)	0.151 NS	0.645**	0.075NS	0.650**
X_6 - Sunshine (hrs.)	0.052 NS	0-.480 NS	0.127 NS	-0.478*

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

Table 23. Correlation between weather parameters and the shoot and capsule borer on cardamom, 2017

Weather Parameters	Correlation coefficient (*r*)			
	ZAHRS, Mudigere		Satish farm, Mudigere	
	Shoot	Capsule	Shoot	Capsule
X1 - Maximum temperature (0C)	0.516*	-0.558 **	0.264 NS	-0.583**
X2 - Minimum temperature (0C)	-0.486 *	-0.155 NS	-0.546**	-0.149 NS
X3 - Relative humidity morning (%)	0.521*	0.475*	-0.037NS	0.470*
X4 - Relative humidity evening (%)	-0.094 NS	0.445*	-0.518*	0.447*
X5 - Rainfall (mm)	-0.011 NS	0.367 NS	-0.075NS	0.387 NS
X6 - Sunshine (hrs.)	-0.088 NS	-0.583**	-0.097NS	-0.612**

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

Satish farm, Mudigere, 2017

Shoot: N=24, $\boldsymbol{R^2}$**= 0.514**, Y_3 (Per cent infestation on shoot) = -10.713 + 2.092(X_1) - 6.078(X_2) + 1.890(X_3) - 0.839(X_4) - 0.130(X_5) - 1.965(X_6)

Capsules: N=24, $\boldsymbol{R^2}$**= 0.500**, Y_4 (Per cent infestation on Capsules) = -36.544 - 0.749(X_1) + 2.041(X_2) + 0.214(X_3) + 0.112(X_4) - 0.327(X_5) - 0.720(X_6)

4.1.1c Seasonal incidence of borer, *C. sahyadriensis* on ginger

Seasonal incidence of borer, *C. sahyadriensis* was recorded at locations *viz*., Hassan, Shivamogga and Kodagu (Table 24). In each of the three districts three ginger plantations were monitored for borer infestations. In Kodagu, only at two places the borer infestations on ginger were recorded. Maximum borer infestation was recorded during September-October, 2016-17. The mean per cent infestation on ginger shoots at Hassan varied from nil to 34.88. In Shivamogga, it was upto 31.87% and in Kodagu, it varied from nil to 30%. This clearly indicated that *C. sahyadriensis* is an economically important pest of ginger and rational practices are needed to contain borer damage in ginger plantations (Table 24).

The pests of turmeric, *Curcuma longa* (Linnaeus) and ginger, *Zingiber officinale* (Rosc.) were surveyed by Patel *et al*. (1988) during 1985-86. The pyralid, *C. sahyadriensis*, is considered a potential pest in the second fortnight of September. A roving survey was conducted by Kotikal and Kulkarni (2000) during 1996-97 at three growth phases of turmeric. Shoot borer was the predominant pest in early vegetative phase (45-60 days) and grand growth stage (100-120 days) of the crop in Raibag, Chikodi, Jamakhandi and Humanabad taluks of Karnataka, India.

On ginger, the borer is known to occur throughout the crop period in Kerala during July to December. In Kottayam and Idukki districts, the damage was higher during August, September, and October (Nybe, 2001). On turmeric, *C. sahyadreinsis* occurred throughout the crop period in Kerala during July to December. The pattern of distribution of *Conogethes* species in a turmeric field at Peruvannamuzhi was random during July to September and became more aggregated during October to December. The symptoms of

Table 24: Seasonal incidence of the borer *C. sahyadriensis* on ginger select locations, 2016-17

Month	Fortnight	Mean % infestation on ginger shoots							
		Hassan			Shivamogga			Kodagu	
		Chikkagondanahalli	Malali	Thattehalli	Bilki	Koratigere	Thadagani	Kushalanagar	Murnadu
June	I	0.00	0.00	0.00	0.00	1.11	0.83	0.00	0.00
	II	0.00	3.12	0.95	2.44	3.78	2.06	2.29	0.00
July	I	3.62	5.06	6.44	5.46	4.51	3.02	4.84	6.79
	II	5.74	9.64	8.08	11.03	4.35	7.95	5.79	7.68
August	I	8.65	13.13	7.80	10.20	20.11	14.97	7.86	12.08
	II	16.29	22.33	18.33	22.75	19.29	15.73	18.17	17.60
September	I	24.79	**34.88**	**20.04**	**28.10**	**29.98**	**24.90**	**21.63**	**23.62**
	II	**30.25**	21.75	**27.37**	**31.87**	**26.73**	**26.11**	**24.08**	**29.59**
October	I	**32.62**	20.08	13.73	**31.40**	**28.67**	17.29	9.11	**23.13**
	II	19.74	15.63	10.19	17.75	15.90	10.11	4.11	12.30
November	I	9.41	6.57	2.29	6.79	4.51	2.29	1.11	6.33
	II	2.44	3.17	2.44	1.33	2.74	2.29	1.90	3.24
	I	1.11	0.95	3.62	0.74	1.11	2.17	0.00	1.90
December	II	0.74	0.00	1.33	0.95	0.00	0.74	0.83	0.95
Jan-2017	I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74
	II	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

n= 15 clumps/plot/15days

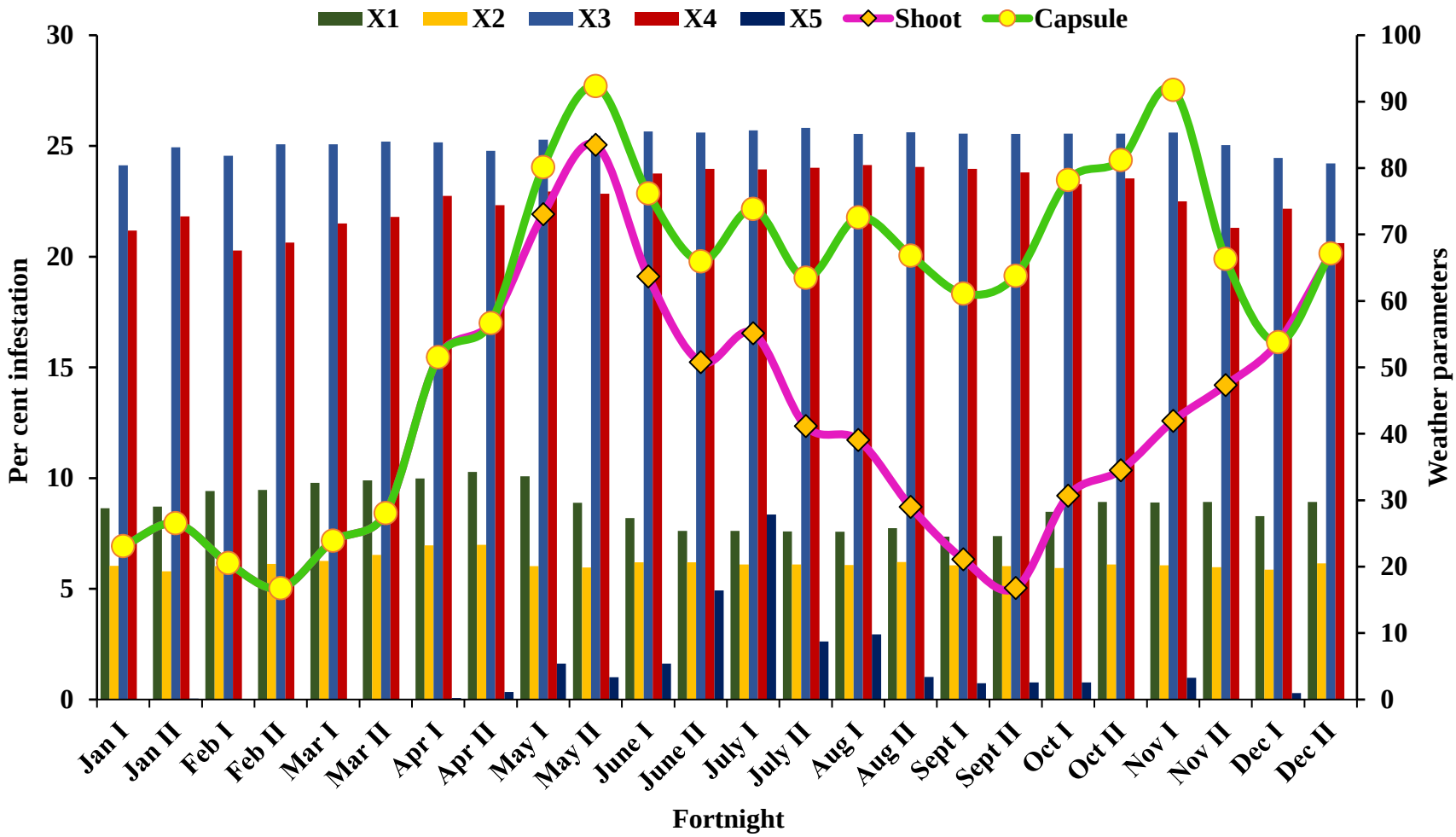

Fig. 1. Seasonal incidence of Cardamom borer, *C. sahyadriensis* in relation to abiotic factors, Mudigere, 2016

X1- Maximum temperature (^{0}C),
X2- Minimum temperature (^{0}C),
X3-Morning relative humidity (%),
X4- Afternoon relative humidity (%),
X5-Rainfall (mm),
n= 15clumps/plot/15days.

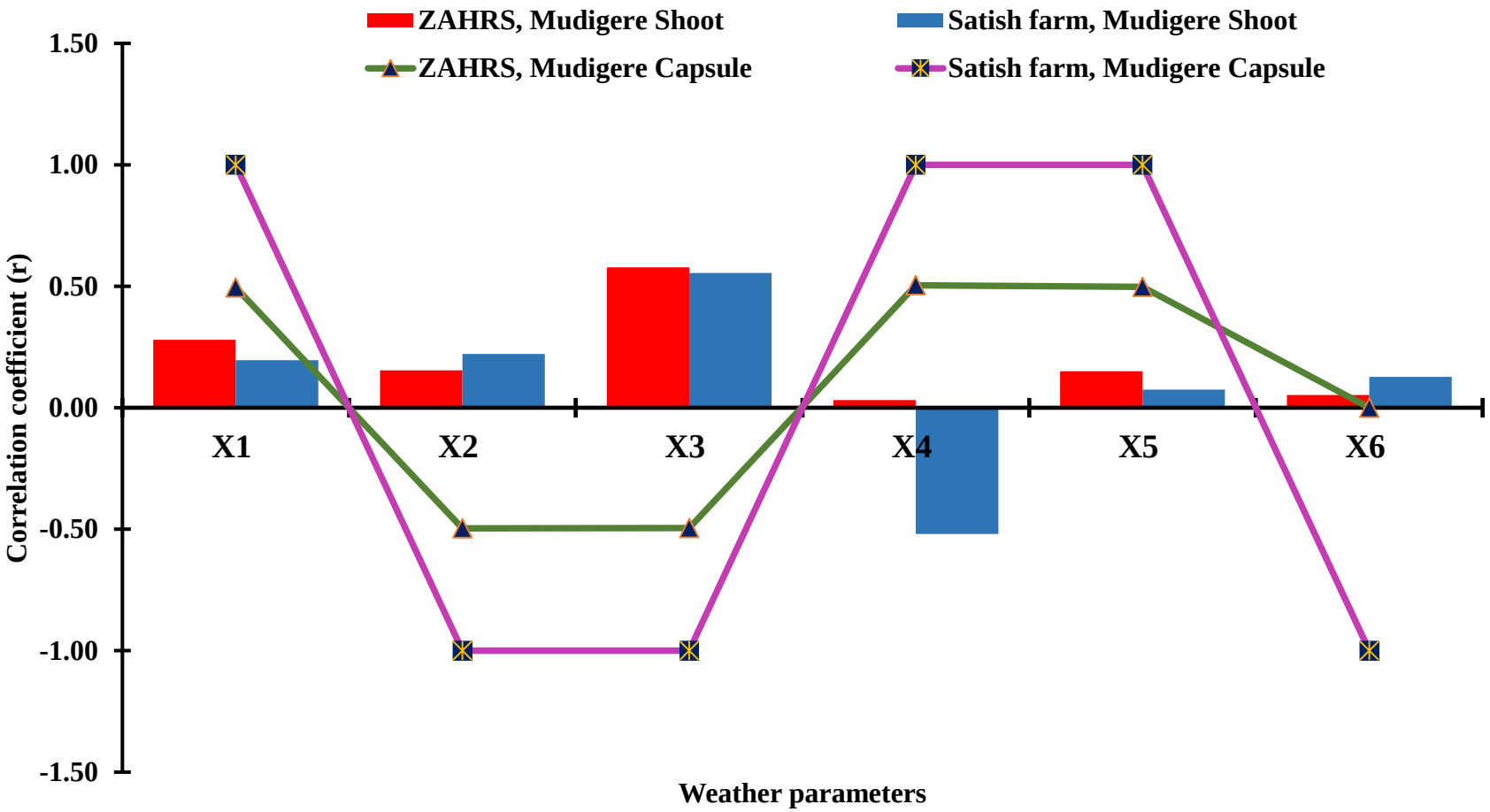

Fig. 2. Correlation coefficient and regression equation between weather parameters (X) and infestation (Y_1 to Y_4), Mudigere, 2016

X1- Maximum temperature (^{0}C),
X2- Minimum temperature (^{0}C),
X3-Morning relative humidity (%),
X4- Afternoon relative humidity (%),
X5-Rainfall (mm),
X6- Sunshine (hrs.)

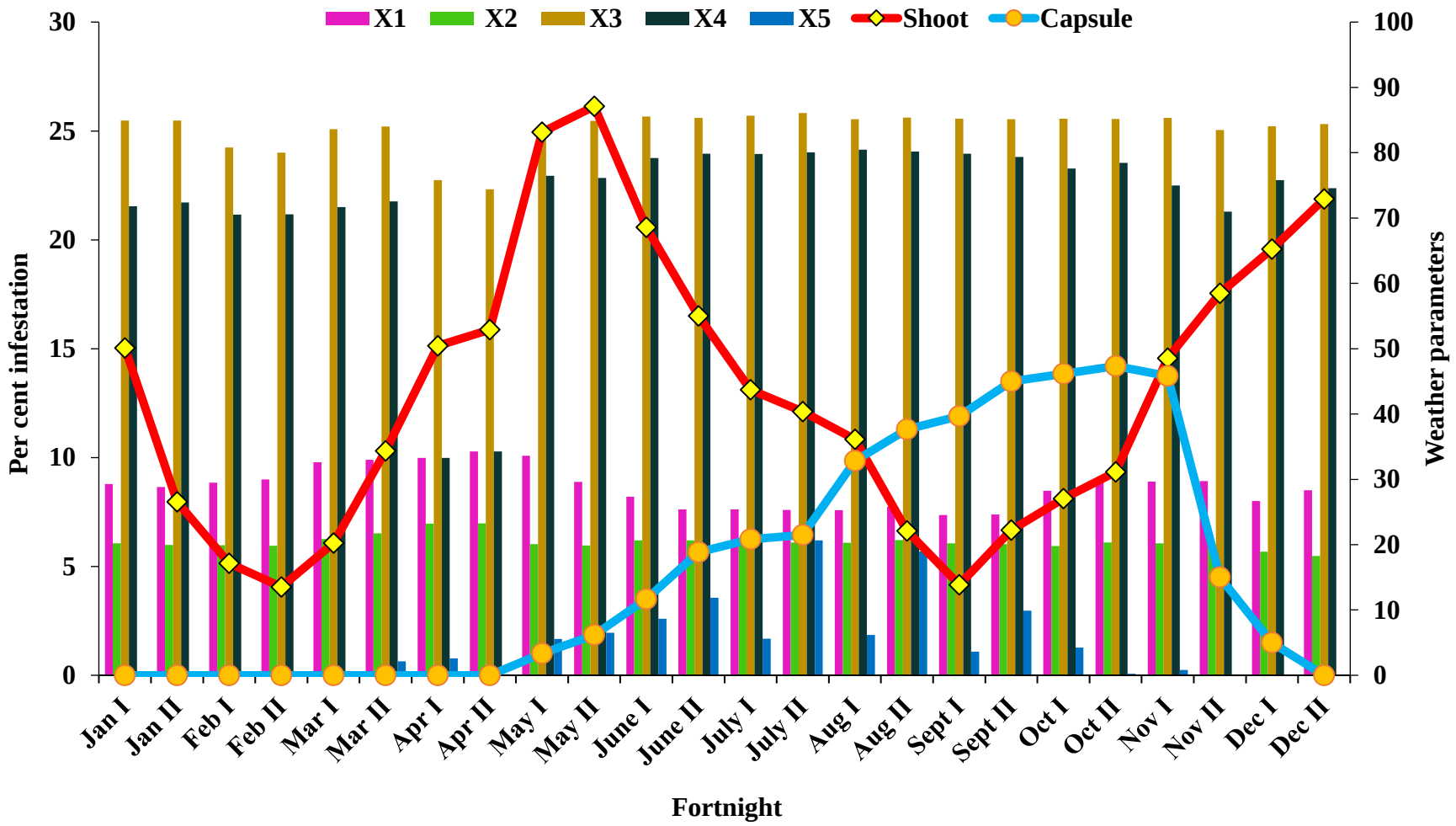

Fig. 3. Seasonal incidence of Cardamom borer, *C. sahyadriensis* in relation to abiotic factors, Mudigere, 2017

X1- Maximum temperature (^{0}C),
X2- Minimum temperature (^{0}C),
X3-Morning relative humidity (%),
X4- Afternoon relative humidity (%),
X5-Rainfall (mm),
n= 15clumps/plot/15days.

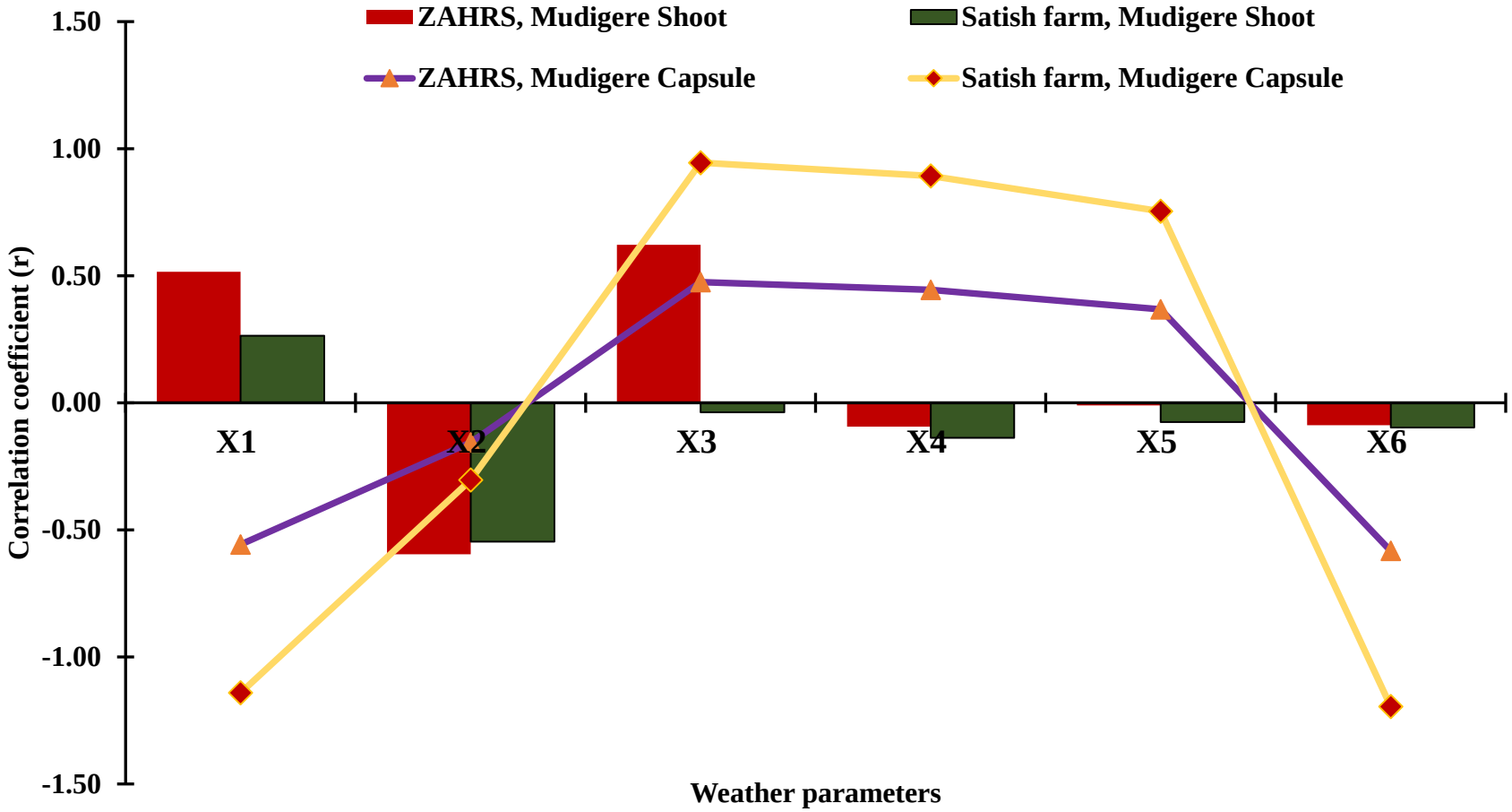

Fig. 4. Correlation coefficient and regression equation between weather parameters (X) and infestation (Y_1 to Y_4), Mudigere, 2017

X1- Maximum temperature (^{0}C),
X2- Minimum temperature (^{0}C),
X3-Morning relative humidity (%),
X4- Afternoon relative humidity (%),
X5-Rainfall (mm),
X6- Sunshine (hrs.)

fresh pest infestation were higher during October to December (Devasahayam *et al.,* 2010a). In India, Devasahayam and Koya (2005) reported that *C. sahyadreinsis* was the most serious pest of ginger, particularly in south India. Crop yields can be significantly affected when more than 45 Per cent of shoots in a clump are damaged (Devasahayam *et al.,* 2010).

4.1.2 Seasonal incidence of *C. punctiferalis* on castor

Based on the observations made at various growth stages of castor, the occurrence of castor shoot and capsule borer on the crop from seedling stage till the harvest of the crop was recorded (Tables 25 and 26) with prevailing weather parameters. The caterpillars were found boring in to tender shoots, inflorescence and tender capsules, fed on the contents of the shoot and capsules and remained inside. The infested pods when opened revealed the presence of caterpillars, excretory pellets and few silken threads. The caterpillars were light brown to pale white with brown head.

The caterpillars were found on the crop during September to March, ZAHRS, Babbur farm, Hiryur, 2016 and 2017. The larval incidence began from September first fortnight and continued till March 2017 first week with a peak density of 4.05 larvae per plant recorded during December first week and minimum density (0.10) during March 2017 first week. *C. punctiferalis* population on castor from March second fortnight was not found (Table 25 and Fig. 5). Whereas, during 2017, the larval incidence got initiated from August second fortnight and continued till February 2018 second week with a peak density of 3.89 larvae per plant recorded during November second fortnight and minimum density (0.09) during February 2018 first week. *C. punctiferalis* population on castor from March 2018 first fortnight was not found (Table 26 and Fig.5).

The caterpillars were found on the crop during September to March, Dryland Agriculture, UAS, GKVK, Bengaluru, 2016 and 2017. The data revealed that larval incidence initiated from August second fortnight and continued till March 2017 first week with a peak density of 3.75 (during 2016) and 3.65 (during 2017) larvae per plant recorded in December first fortnight and November second fortnight, respectively. Minimum density (0.05) was recorded during March 2017 first week and density (0.60) larvae per

plant during February 2018 second fortnight, respectively. *C. punctiferalis* population on castor was not found from March month onwards (Tables 28 and 29).

4.1.2a Correlation between incidence of *C. punctiferalis* and abiotic factors

To elucidate the role of weather parameters on castor shoot and capsule borer infestations, correlation analyses between weather parameters and capsule borer were run. Castor shoot and capsule borer population at ZAHRS, Babbur farm, Hiryur was significantly negatively correlated with minimum temperature (r= -0.529 during 2016), maximum temperature (r= -0.688 during 2017), evening relative humidity (r= -0.629 during 2016) and sunshine hours (r= -0.552 during 2017) (Table 27 and Fig. 6). Whereas, correlation of larval population with weather parameters was significantly and positively correlated with sunshine hours (r= 0.568 during 2016) and evening relative humidity (r= 0.561 during 2017) (Table 27 and Fig. 6). Thus, temperature, relative humidity and sunshine hours together impacted borer infestations on castor in Babbur farm, Hiryur.

Castor shoot and capsule borer population at Dryland Agriculture, UAS, GKVK, Bengaluru was significantly and negatively correlated with minimum temperature (r= -0.571 during 2016 and 2017), evening relative humidity (r= -0.588 during 2016 and r= -0.590 during 2017) and morning relative humidity (r= -0.531 during 2017) (Table 30). Thus, weather parameters like temperature, and relative humidity significantly influenced borer infestations on castor in GKVK, Bengaluru.

4.1.2b Regression between incidence of *C. punctiferalis* and abiotic factors

The regression co-efficient of the castor shoot and capsule borer on plants at ZAHRS, Babbur farm and Dryland Agriculture, GKVK, Bengaluru were found to be highly significant statistically. The multiple regression equation fitted with *C. punctiferalis* and weather parameter of the year 2016 - 2017 to predict the castor shoot and capsule borer population (Y) was

ZAHR, Babbur farm, Hiryur, 2016: N=15, $\boldsymbol{R^2}$**= 0.823**, Y (Larvae/plant) = 10.775 - 0.279(X_1) - 0.081 (X_2) - 0.030(X_3) - 0.005(X_4) - 0.183(X_5) + 0.148(X_6) - 0.845(X_7)

ZAHR, Babbur farm, Hiryur, 2017: *N*=15, $\boldsymbol{R^2}$**= 0.888**, Y (Larvae/plant) = 29.712 - 0.540(X_1) -0.042(X_2) -0.096(X_3) + 0.037 (X_4) -0.138((X_5) -1.480(X_6) - 0.332(X_7)

GKVK, Bengaluru, 2016: *N*=15, $\boldsymbol{R^2}$**= 0.707**, Y (Larvae/plant) = 14.745 + 0.048(X_1) - 0.637(X_2) -0.065(X_3) +0.070(X_4) + 0.045((X_5) -0.207(X_6)

GKVK, Bengaluru, 2017: *N*=15, $\boldsymbol{R^2}$**= 0.649**, Y (Larvae/plant) = 12.037 + 0.239(X_1) - 0.722(X_2) - 0.090(X_3) +0.107 (X_4) -0.078((X_5) -0.321(X_6)

These results are in accordance with Srivastava and Awasthi (1961) who observed that the larvae of *C. punctiferalis* entered a quiescent stage during December, January and first half of February and over wintering larvae resumed their activity when exposed to a 25°C. Mishra and Teotia (1965) studied seasonal incidence of capsule borer which revealed that the pest was generally active on main crop season with occurrence of all stages from March to April. Castor shoot and capsule borer was found all through the year and was usually severe during November to March on the main crop season (Rai, 1976).

Madhuri (2005) reported that the activity of shoot and capsule borer was observed initially during the last week of January and capsule infestation reached peak level by first week of March. The correlation between capsule infestation and mean maximum temperature was significant and positive while relative humidities had significant negative correlation and rainfall had non-significant negative and non-significant correlation. The shoot and capsule borer, peak per cent infestation of capsule was recorded on April during 2008. The correlation was positive and significant for shoot and capsule borer for mean maximum temperature/minimum temperature. The pest population of castor borer exhibited negative and significant effect with relative humidity (Naveen 2009). Ganesha (2011) observed castor shoot and capsule borer population had significant negative relationship with maximum temperature of the same fortnight, positive correlation with morning and evening relative humidity, but there is no relationship was found with any weather parameters.

Table 25. Seasonal incidence of shoot and capsule borer, *C. punctiferalis* on castor at ZAHR, Babbur farm, Hiryur, 2016

Months	Fortnight	Larvae/ plant	Temperature (ºC)		Relative humidity (%)		Rainfall (mm)	Windspeed (km/hr.)	Sunshine (hrs.)
			Max.	Min.	Morning	Evening			
August	I	0	28.49	23.76	85.26	72.18	0.00	3.68	4.93
	II	0	30.25	22.96	88.99	67.64	0.24	3.24	5.84
September	I	0.75	29.69	23.13	88.50	69.04	0.05	3.59	4.83
	II	1.50	28.88	23.43	83.58	72.80	0.40	3.64	6.05
October	I	2.00	31.33	22.45	87.05	61.02	0.92	2.26	7.35
	II	2.28	32.21	19.39	75.02	49.14	0.00	0.97	9.17
November	I	2.77	31.35	17.07	72.43	51.80	0.00	1.04	8.82
	II	3.52	31.71	15.59	74.24	39.14	0.00	1.17	8.46
December	I	4.05	29.01	16.35	84.22	49.98	1.92	1.21	5.71
	II	3.45	30.58	13.98	81.66	34.74	0.00	1.00	9.06
Janaury-17	I	2.50	30.29	12.56	76.55	38.13	8.32	0.00	0.71
	II	1.35	30.18	14.25	80.43	43.06	7.69	0.00	1.67
Febraury-17	I	1.08	32.40	13.88	79.17	48.19	9.53	0.00	1.13
	II	0.45	34.02	15.02	74.23	48.17	8.97	0.00	1.66
March-17	I	0.10	35.31	19.64	76.38	58.49	8.31	0.00	1.43
	II	0.00	36.31	22.19	84.50	58.92	8.00	0.08	1.42

n= 10 plants/plot/15 days

Table 26. Seasonal incidence of shoot and capsule borer, *C. punctiferalis* on castor at ZAHR, Babbur farm, Hiryur, 2017

Months	Fortnight	Larvae/ plant	Temperature (ºC)		Relative humidity (%)		Rainfall (mm)	Windspeed (km/hrs.)	Sunshine (hrs.)
			Max.	Min.	Morning	Evening			
August	I	0	31.95	21.67	82.60	63.43	1.53	3.11	5.10
	II	0.05	30.58	21.65	83.55	66.60	2.33	3.23	3.88
September	I	0.93	31.73	21.88	84.47	63.95	4.17	1.34	5.54
	II	1.75	30.06	20.88	83.56	70.43	6.49	2.09	3.89
October	I	2.16	29.77	21.53	88.30	72.85	19.39	0.60	4.19
	II	2.75	30.50	20.50	82.79	57.05	0.00	0.92	7.08
November	I	3.48	28.91	18.61	85.91	63.69	0.13	0.99	5.95
	II	3.89	31.01	18.91	83.91	54.09	0.00	0.79	6.38
December	I	3.10	30.27	17.69	85.11	57.82	0.00	1.00	6.61
	II	2.54	29.45	13.76	84.67	44.14	0.00	1.18	9.05
Janaury-18	I	2.06	31.04	14.83	83.60	45.87	0.00	0.80	8.87
	II	1.40	30.69	13.63	82.87	43.00	0.00	0.88	9.19
Febraury-18	I	0.75	31.68	16.03	84.27	39.33	0.08	0.91	8.15
	II	0.09	33.14	14.17	74.00	31.54	0.00	1.24	9.30
March-18	I	0.00	35.41	15.00	64.33	24.00	0.00	1.28	8.81

n= 10 plants/plot/15 days

Table 27. Correlations between weather parameters and castor capsule borer at ZAHR, Babbur farm, Hiryur, 2016 to 2017

Weather Parameters	Correlation coefficient (*r*)	
	2016	**2017**
X_1 - Maximum temperature (^{0}C)	-0.346 NS	-0.688**
X_2 - Minimum temperature (^{0}C)	-0.529*	-0.074 NS
X_3 - Morning RH (%)	-0.315 NS	0.472 NS
X_4 - Evening RH (%)	-0.629**	0.561*
X_5 - Rainfall (mm)	-0.367 NS	-0.076 NS
X_6 - Sunshine (hrs.)	0.568*	-0.552*
X_7 - Wind speed (km/hr)	-0.170 NS	0.165 NS

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

Multiple linear regression equations

ZAHR, Babbur farm, Hiryur, 2016: *N*=15, $\boldsymbol{R^2}$**= 0.823**, Y (Larvae/plant) = 10.775 - 0.279(X_1) - 0.081 (X_2) - 0.030(X_3) - 0.005(X_4) - 0.183(X_5) + 0.148(X_6) - 0.845(X_7)

ZAHR, Babbur farm, Hiryur, 2017: *N*=15, $\boldsymbol{R^2}$**= 0.888**, Y (Larvae/plant) = 29.712 - 0.540(X_1) -0.042(X_2) -0.096(X_3) + 0.037 (X_4) - 0.138((X_5) - 1.480(X_6) - 0.332(X_7)

Table 28. Seasonal incidence of shoot and capsule borer, *C. punctiferalis* on castor at Dryland Agriculture, UAS, GKVK, Bengaluru, 2016

Month	Fortnight	Larvae/plant	Temperature (°C)		Relative humidity (%)		Rain fall (mm)	Sunshine (hrs.)
			Max.	Min.	Morning	Evening		
August	I	0.00	27.59	19.05	92.67	55.87	1.41	6.44
	II	0.54	28.70	19.80	91.44	52.63	0.36	5.19
September	I	0.89	27.76	18.90	90.77	54.00	1.19	3.91
	II	1.00	27.83	19.11	94.00	55.00	2.19	3.29
October	I	1.58	29.75	17.26	92.20	49.53	2.06	6.81
	II	1.75	29.93	15.25	77.44	45.69	0.00	9.11
November	I	2.41	29.33	17.21	82.33	46.27	0.00	8.49
	II	3.10	29.90	15.30	82.00	39.00	0.00	8.31
December	I	3.75	26.50	15.30	85.00	50.00	4.90	4.50
	II	3.29	27.80	14.20	89.00	42.00	0.05	9.30
Janaury-17	I	2.40	27.20	13.70	88.70	41.40	0.00	9.00
	II	1.25	27.50	15.20	89.10	37.60	0.00	7.70
Febraury-17	I	1.10	29.80	14.50	85.10	34.90	0.00	10.00
	II	1.02	31.50	15.50	82.40	32.10	0.00	9.80
March-17	I	0.05	32.30	18.60	82.60	38.90	0.70	9.00
	II	0.00	33.60	20.30	81.10	38.50	0.00	9.00

n= 10 plants/plot/15 days

Table 29. Seasonal incidence of shoot and capsule borer, *C. punctiferalis* on castor at Dryland Agriculture, UAS, GKVK, Bengaluru, 2017

Month	Fortnight	Larvae/plant	Temperature (ºC)		Relative humidity (%)		Rain fall (mm)	Sunshine (hrs.)
			Max.	Min.	Morning	Evening		
August	I	0	27.59	19.05	92.67	55.87	1.41	6.44
	II	0.15	28.70	19.80	91.44	52.63	0.36	5.19
September	I	0.77	27.76	18.90	90.77	54.00	1.19	3.91
	II	1.10	27.83	19.11	94.00	55.00	2.19	3.29
October	I	1.80	29.75	17.26	92.20	49.53	2.06	6.81
	II	2.15	29.93	15.25	77.44	45.69	0.00	9.11
November	I	2.64	29.33	17.21	82.33	46.27	0.00	8.49
	II	3.65	29.90	15.30	82.00	39.00	0.00	8.31
December	I	3.20	26.50	15.30	85.00	50.00	4.90	4.50
	II	2.55	27.80	14.20	89.00	42.00	0.05	9.30
Jan-17	I	1.60	27.20	13.70	88.70	41.40	0.00	9.00
	II	1.20	27.50	15.20	89.10	37.60	0.00	7.70
Feb-18	I	1.00	29.80	14.50	85.10	34.90	0.00	10.00
	II	0.60	31.50	15.50	82.40	32.10	0.00	9.80
Mar-18	I	0.00	32.30	18.60	82.60	38.90	0.70	9.00

n= 10 plants/plot/15 days

Table 30. Correlations between weather parameters and castor capsule borer at GKVK, Bengaluru, 2016 to 2017

Weather Parameters	Correlation coefficient (*r*)	
	2016	**2017**
X_1 - Maximum temperature (^{0}C)	-0.218 NS	-0.22 NS
X_2 - Minimum temperature (^{0}C)	-0.571 **	-0.571**
X_3 - Morning RH (%)	-0.588 **	-0.59 *
X_4 - Evening RH (%)	-0.112 NS	-0.531 *
X_5 - Rainfall (mm)	0.167 NS	0.17 NS
X_6 - Sunshine (hrs.)	0.112 NS	0.11NS

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

Multiple linear regression equations

GKVK, Bengaluru, 2016: *N*=15, R^2**= 0.707**, Y (Larvae/plant) = 14.745 + 0.048(X_1) - 0.637(X_2) -0.065(X_3) +0.070(X_4) + 0.045((X_5) -0.207(X_6)

GKVK, Bengaluru, 2017: *N*=15, R^2**= 0.649**, Y (Larvae/plant) = 12.037 + 0.239(X_1) - 0.722(X_2) -0.090(X_3) +0.107 (X_4) -0.078((X_5) -0.321(X_6)

4.1.2c Per cent infestation of *C. punctiferalis* on castor

The maximum borer infestations on castor capsule was recorded in Gangasagar, Tumkur (46.24%), ZAHRS, Babbur farm, Hiryur (40.08%) and Dryland Agriculture, GKVK, Bengaluru (34.49%) during November-December, 2016. Similarly during 2017, maximum borer damage was recorded in November (44.11%). In ZAHRS, Babbur farm and Dryland Agriculture, GKVK, Bengaluru also maximum borer infestations were recorded during November and December, 2017 (Table 31). This data suggested that castor borer is a major pest on castor incurring economical yield losses.

Seasonal incidence data of the borer on cardamom, castor and ginger showed that depending on weather and micro-habitat conditions, the peak occurrence of the pests varied slightly on the above three crops at Mudigere, Chitradurga, Tumkur and Bengaluru

conditions. The transformation of plant vegetative phase to reproductive phase is crucial for the sustenance of borer infestations on the above three crops.

The damage on castor was 16 per cent to 72 per cent (Bilapate and Talati, 1977). Goel and Kumar (1990) reported that maximum and minimum temperature influenced positively with significant effect on per cent infestation of capsule by shoot and capsule borer, *C. punctiferalis*. Asokan and Kempuchetty (2000) reported that incidence of capsule borer, *C. punctiferalis* started from November-December with 1 to 3 per cent capsule damage in the rainfed castor as intercrop. The peak period of damage was more during January-February and extended up to March – April. Tirupati Reddy (2002) reported that the initial incidence of the infestation of capsule by *C. punctiferalis* started in first week of February with 14.16 per cent and the maximum damage of capsules was observed during last week of March (32.94 per cent) capsule infestation. The relationship between the weather parameters and capsule infestation was significant and positive between percent infestation of capsule and maximum temperature/minimum temperature, while negative and significant relation was found between infestation and humidity. Castor borer damage on capsule leads to upto 27% of yield loss (Shashank *et al.*, 2015). Suganthy (2011) estimated capsule yield loss in castor in Tamil Nadu was 10.80 –26.70 per cent and estimated 42.30 per cent crop loss in India (Kapadia, 1996).

4.1.3 Relationship between number of male moths trapping and abiotic factors

Studies on seasonal incidence of *C. punctiferalis* on castor provide information on the initiation and extent of damage at different growth stages of the crop and its relation to weather parameters which will be of great help to plan appropriate management.

An attempt was made to correlate moth catches with abiotic factors at GKVK from Bengaluru 2016 to 2017 and ZAHRS, Babbur farm, Hiryur 2017. The abiotic factors *viz*., Maximum and Minimum temperature at morning and evening RH (%), wind speed km/hr), sunshine (hrs.), Rainfall (mm) and evaporation were considered for correlated analysis with moth catches. The data on weather parameters and moth catches of *C. punctiferalis* are presented in Tables 32 to 37.

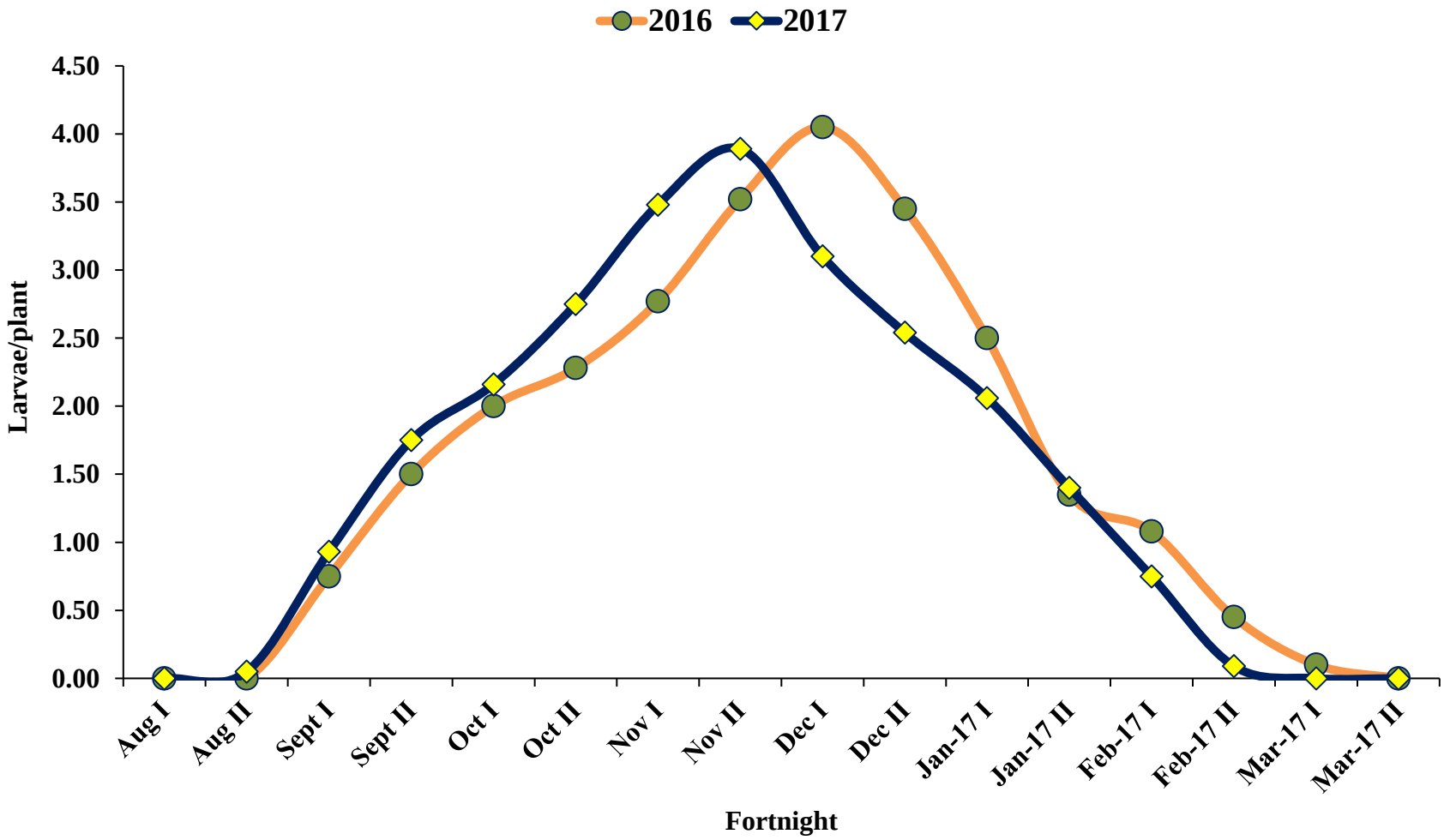

Fig. 5. Occurrence of shoot and capsule borer, *C. punctiferalis* on castor crop, ZAHRS, Hiryur, 2016–2017.

(n=10 plants/plot/15 days)

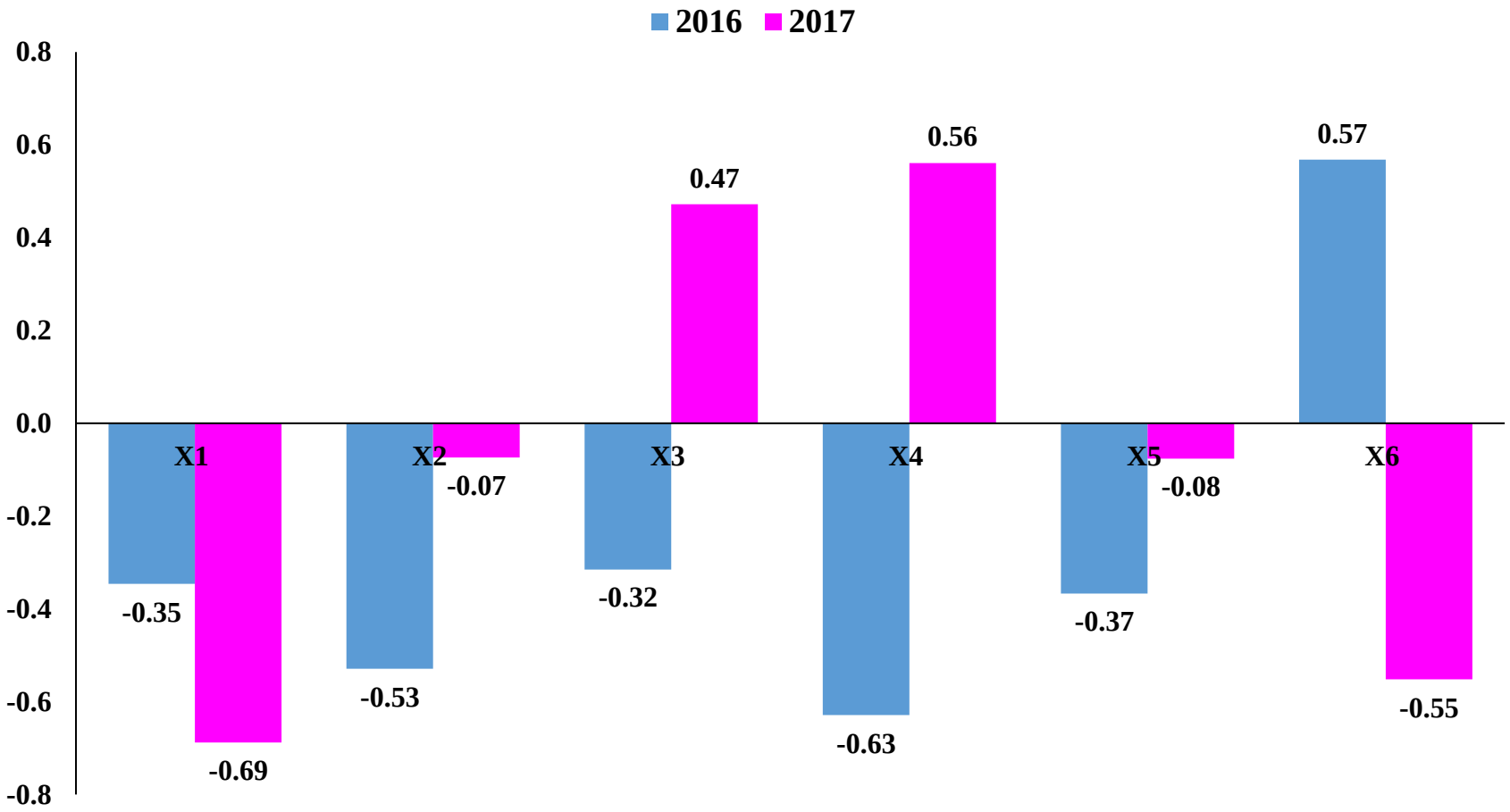

Fig. 6. Correlation coefficient and regression equation between weather parameters (X) and larvae/plant (Y_1), ZAHRS, Hiryur, 2016-2017

X1- Maximum temperature (^{0}C),
X2- Minimum temperature (^{0}C),
X3-Morning relative humidity (%),
X4- Afternoon relative humidity (%),
X5-Rainfall (mm),
X6- Sunshine (hrs.)

Table 31. Seasonal incidence of shoot and capsule borer, *C. punctiferalis* on castor at select locations, 2016 to 2017

Month	Fortnight	Mean % infestation on castor capsule											
		Gangasagar, Pavagada (Tq), Tumkur				ZAHRS, Babbur farm, Hiryur, Chitradurga				Dryland Agriculture, UAS, GKVK, Bengaluru			
		2016		2017		2016		2017		2016		2017	
		capsule	shoot	capsule	shoot	capsule	shoot	capsule	shoot	capsule	shoot	capsule	shoot
August	I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	II	0.00	0.50	0.00	0.19	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00
September	I	0.80	0.00	1.30	0.32	0.60	0.15	0.94	0.85	0.00	0.00	0.94	0.00
	II	2.97	1.23	3.91	1.08	2.97	0.00	3.53	0.00	2.22	0.65	3.02	0.00
October	I	6.67	1.00	7.16	0.31	10.40	0.67	12.25	0.70	7.42	0.00	9.21	0.95
	II	13.67	2.55	14.78	1.50	19.21	1.85	21.39	1.54	14.39	1.40	17.54	1.50
November	I	17.39	1.75	22.36	1.45	26.57	1.50	23.98	2.18	22.51	2.10	26.23	2.35
	II	28.85	**2.78**	**44.11**	**2.88**	**36.67**	1.98	**38.27**	1.85	28.35	1.50	32.23	1.90
December	I	**46.24**	**3.80**	**39.56**	**2.60**	**40.08**	**2.46**	**42.23**	**2.76**	**34.49**	**2.85**	**38.86**	**3.25**
	II	**41.90**	2.00	**29.13**	2.30	**32.61**	**2.10**	**31.39**	**3.10**	**30.14**	1.89	**34.98**	1.45
January	I	32.36	1.15	15.75	1.50	26.20	1.00	22.11	2.08	18.59	2.00	26.68	2.36
	II	21.96	0.00	10.79	2.10	15.54	0.00	12.86	0.75	11.10	1.75	12.31	1.50
February	I	7.29	1.45	2.32	0.75	6.76	0.50	5.18	1.00	3.86	0.91	5.12	0.70
	II	1.33	0.00	0.00	0.00	2.40	0.00	2.07	0.45	2.90	0.25	1.79	1.00
March	I	0.18	0.00	0.00	0.00	1.42	0.20	0.00	0.00	1.24	0.00	0.70	0.00
	II	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.22	0.00	0.00	0.00

n= 10 plants/plot/15 day

4.1.3a Dryland Agricultural Research Station, GKVK, 2016

Relative humidity, sun shine hours and rainfall were correlated with moth catches. Evaporation also to some extent influenced moth catches at Dryland Agricultural Research Station, GKVK Bengaluru. In general, lower to moderate numbers of moths were trapped between November to December 2016. In rest of the period lower numbers of moths were trapped *i.e.*, on an average less than one moth per trap. The trap catches were recorded from the first week of trap installation. Maximum number of (4.5 moths per trap) moth trapping was recorded during 46th standard week and then the moth catches declined gradually. Thereafter minimum number of moths (<1 moth per trap) was recorded during 7th standard week (Table 32 and Fig. 7).

The data on moth catches was correlated with prevailing temperature, relative humidity, wind speed, sunshine (hrs.). The moth catches had a significant association with minimum temperature (r=0.660) and morning relative humidity (r=606); while moth catches were negatively influenced by rainfall, windspeed and sunshine hours (Table 33). When the data was subjected to linear regression analysis it revealed that, the coefficient of determination (R^2) for *C. punctiferalis* population was 0.839, which showed that abiotic factors together were able to explain the variation in the population of *C. punctiferalis* the extent of 83.90 out of 100 and the following equation was arrived at.

$$Y \text{ (Moth catches)} = -55.177 + 1.630(X_1) - 0.142(X_2) + 0.086(X_3) + 0.228(X_4) + 0.302(X_5) - 0.071(X_6) + 0.008(X_7) - 1.332(X_8)$$

4.1.3b Dryland Agricultural Research Station, GKVK, 2017

The trap catches were recorded from the first week of trap installation. Maximum number of (4.75 moths per trap) moth trapping was recorded during 47th standard week and then the moth catches declined gradually. Thereafter minimum number of moths (<1 moth per trap) was recorded during 7th standard week (Table 34 and Fig. 7).

The data on moth catches was correlated with prevailing temperature, relative humidity, wind speed, sunshine (hrs.). The moth catches had a significant association with minimum temperature (r=0.545) and negatively influenced by morning relative humidity,

rainfall, windspeed and sunshine hours (Table 35). When the data was subjected to linear regression analysis it revealed that, the coefficient of determination (R^2) for *C. punctiferalis* population was 0.580, which showed that abiotic factors together were able to explain the variation in the population of *C. punctiferalis* the extent of 58.00 out of 100 and the following equation was arrived at.

Y (Moth catches) = $- 63.027 + 1.585 (X_1) + 0.056(X_2) - 0.019(X_3) + 0.475(X_4) - 0.351(X_5) + 0.442(X_6) - 0.105(X_7) - 1.216(X_8)$

4.1.3c ZAHRS, Babbur farm, Hiryur, 2017

The trap catches were recorded from the third week of trap installation. Maximum number of (4.25 moths per trap) moth trapping was recorded during 48th standard week and then the moth catches declined gradually (Table 36 and Fig. 8).

The data on moth catches was correlated with prevailing temperature, relative humidity, wind speed, sunshine (hrs.). In general, lower to moderate numbers of moths were trapped between November to December 2017. In rest of the period, lower numbers of moths were trapped *i.e.*, on an average less than one moth per trap (Table 37). When the data was subjected to linear regression analysis it revealed that, the coefficient of determination (R^2) for *C. punctiferalis* population was 0.780, which showed that abiotic factors together were able to explain the variation in the population of *C. punctiferalis* the extent of 78.00 out of 100 and the following equation was arrived.

Y (Moth catches) = $15.420 + 0.229(X_1) - 0.350(X_2) - 0.029(X_3) - 0.004(X_4) - 0.197(X_5) - 0.925(X_6) - 10.284(X_7) - 1.124(X_8)$

Table 32. Castor shoot and capsule borer moth catches in relation with abiotic factors at GKVK, Bengaluru, 2016

Date of observations	SMW	*Mean number of moth catches	Temperature (ºC)		Relative humidity (%)		Wind speed (km/hr.)	Sunshine (hrs.)	Rainfall (mm)	Evaporation (mm)
			Max.	Min.	Morning	Evening				
04-11-2016	44	0.50	29.30	16.20	82.00	42.00	6.50	8.50	0.00	5.30
10-11-2016	45	1.25	29.40	15.80	79.00	45.00	4.70	9.60	0.00	5.30
17-11-2016	46	4.50	29.50	18.40	83.00	46.00	7.70	7.20	0.00	4.20
24-11-2016	47	2.55	29.70	15.80	80.00	39.00	6.70	8.70	0.00	4.30
01-12-2016	48	3.65	30.40	12.70	82.00	36.00	4.00	8.70	0.00	4.10
08-12-2016	49	0.50	27.20	16.40	84.80	45.30	7.70	4.70	0.00	4.10
15-12-2016	50	2.00	25.30	14.60	87.00	56.60	7.20	4.70	57.40	3.50
22-12-2016	51	1.00	27.60	14.70	87.70	41.50	5.50	8.60	0.80	4.20
29-12-2016	52	0.25	28.10	13.30	91.00	39.80	5.10	9.70	0.00	3.90
05-01-2017	1	0.00	27.40	12.20	86.00	41.00	5.20	9.40	0.00	4.20
11-01-2017	2	0.25	27.20	15.10	91.00	42.00	5.10	8.20	0.00	4.10
18-01-2017	3	0.50	26.80	14.10	93.00	39.00	8.50	9.40	0.00	3.80
25-01-2017	4	0.25	27.30	15.40	85.00	39.00	9.70	5.80	0.00	4.10
01-02-2017	5	0.75	29.10	11.90	90.00	39.00	4.80	10.50	0.00	5.30
07-02-2017	6	0.25	29.90	13.90	82.90	34.00	6.50	10.30	0.00	4.90
15-02-2017	7	0.00	29.90	14.60	83.80	33.60	10.20	10.00	0.00	6.90
Max.		4.50	30.40	18.40	93.00	56.60	10.20	10.50	57.40	6.90
Min.		0.00	25.30	11.90	78.00	33.60	3.70	4.70	0.00	3.50
Mean		1.14	28.38	14.69	85.51	41.18	6.57	8.38	3.64	4.51

*SMW- Standard Meteorological Weeks, * mean number of moths captured for seven days in yellow delta traps*

Table 33. Relationship between C. *punctiferalis* moth catches in castor field with abiotic factors at GKVK, Bengaluru, 2016

Variables		Temperature (ºC)		Relative humidity (%)		Wind speed (km/h)	Sunshine (hrs.)	Rainfall (mm)	Evaporation (mm)
		Max.	Min.	Morning	Afternoon				
Mean moth catches		0.320 NS	0.660 *	-0.486 *	0.274 NS	-0.158 NS	-0.223 NS	0.170 NS	-0.272 NS
Temperature (ºC)	**Max. (X_1)**	1	0.042 NS	-0.615*	-0.623**	-0.175NS	0.582*	-0.568*	0.612*
	Min. (X_2)		1	-0.418 NS	0.372 NS	0.425 NS	-0.500*	-0.015 NS	-0.012 NS
Relative humidity (%)	**Morning (X_3)**			1	0.043 NS	-0.020 NS	0.059 NS	0.098 NS	-0.360 NS
	Afternoon (X_4)				1	-0.052 NS	-0.686**	0.751**	-0.466 NS
Wind speed (km/h) (X_5)						1	-0.360 NS	.090 NS	0.212 NS
Sunshine (hrs.) (X_6)							1	-0.529*	0.511*
Rainfall (mm) (X_7)								1	-0.322 NS
Evaporation (mm) (X_8)									1

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); NS- Non significant.*

Multiple linear regression equation:

N=16, $\boldsymbol{R^2}$**= 0.839**, Y (Moth catches) = - 55.177 + 1.630(X_1) -0.142(X_2) + 0.086(X_3) +0.228(X_4) + 0.302(X_5) -0.071(X_6) + 0.008(X_7) - 1.332(X_8)

Table 34. Castor shoot and capsule borer moth catches in relation with abiotic factors at GKVK, Bengaluru, 2017

Date of observations	SMW	*Mean number of moth catches	Temperature (ºC)		Relative humidity (%)		Wind speed (km/hr.)	Sunshine (hrs.)	Rainfall (mm)	Evaporation (mm)
			Max.	Min.	Morning	Evening				
02-11-2017	44	0.25	26.90	17.50	90.00	60.00	6.40	5.40	0.00	4.00
09-11-2017	45	1.34	25.70	17.60	94.00	64.00	7.30	4.60	11.40	3.50
15-11-2017	46	3.15	27.20	16.90	86.00	58.00	4.40	4.60	0.00	4.00
22-11-2017	47	4.75	28.30	18.20	90.00	55.00	5.40	8.20	0.00	4.30
02-12-2017	48	3.95	27.30	16.60	91.00	60.00	7.90	5.40	0.00	4.10
09-12-2017	49	1.50	26.00	16.20	90.90	55.70	4.80	7.70	0.00	3.20
14-12-2017	50	2.10	27.70	16.10	87.00	52.80	4.30	7.50	0.00	4.40
21-12-2017	51	1.20	26.30	13.70	89.40	57.50	7.50	9.00	0.00	4.80
30-12-2017	52	0.25	26.20	13.20	88.90	56.70	5.60	9.00	0.00	4.90
06-01-2018	1	0.50	26.80	14.80	88.00	56.00	4.50	8.10	0.00	4.90
13-01-2018	2	0.00	27.30	14.90	83.00	51.00	6.30	8.20	0.00	4.70
20-01-2018	3	0.25	27.80	13.30	86.00	51.00	5.60	9.50	0.00	4.70
27-01-2018	4	1.50	27.60	14.00	88.00	51.00	4.50	8.90	0.00	4.70
03-02-2018	5	0.85	29.40	15.30	86.00	48.00	7.50	9.50	0.00	4.60
09-02-2018	6	1.00	29.00	16.40	87.70	50.40	5.80	7.40	0.30	4.90
16-02-2018	7	0.50	29.20	16.40	85.00	48.50	8.20	9.60	0.00	5.30
Max.		4.75	29.40	18.20	94.00	64.00	8.20	9.60	11.40	5.30
Min.		0.00	25.70	13.20	83.00	48.00	4.30	4.60	0.00	3.20
Mean		1.64	27.54	15.84	88.52	55.27	6.13	7.78	1.36	4.49

*SMW- Standard Meteorological Weeks, * mean number of moths for seven days in four traps*

Table 35. Relationship between C. *punctiferalis* moth catches in castor field with abiotic factors at GKVK, Bengaluru, 2017

Variables		Temperature (°C)		Relative humidity (%)		Wind speed (km/hr.)	Sunshine (hrs.)	Rainfall (mm)	Evaporation (mm)
		Max.	Min.	Morning	Afternoon				
Mean moth catches		0.069 NS	0.545*	0.343 NS	0.496 *	-0.112 NS	-0.390 NS	-0.022 NS	-0.375 NS
Temperature (°C)	**Max. (X_1)**	1	0.124 NS	-0.577*	-0.786**	0.186 NS	0.404 NS	-0.397 NS	0.535*
	Min. (X_2)	-	1	0.368 NS	0.352 NS	0.114 NS	-0.661**	0.326	-0.538*
Relative humidity (%)	**Morning (X_3)**	-	-	1	0.782**	0.110 NS	-0.492 NS	0.571*	-0.634**
	Afternoon (X_4)	-	-	-	1	0.058 NS	-0.766**	0.534*	-0.633**
Wind speed (km/h) (X_5)		-	-	-	-	1	0.031 NS	0.258 NS	0.141 NS
Sunshine (hrs.) (X_6)		-	-	-	-	-	1	-0.471 NS	0.682**
Rainfall (mm) (X_7)		-	-	-	-	-	-	1	-0.443 NS
Evaporation (mm) (X_8)		-	-	-	-	-	-	-	1

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); NS- Non significant.*

Multiple linear regression equation:

N=16, $\boldsymbol{R^2=0.580}$, Y (Moth catches) = - 63.027 + 1.585 (X_1) + 0.056(X_2) -0.019(X_3) +0.475(X_4) - 0.351(X_5) + 0.442(X_6) - 0.105(X_7) -1.216(X_8)

Table 36. Castor shoot and capsule borer moth catches in relation with abiotic factors at ZAHRS, Babbur farm, Hiryur, 2017

Date of observation	SMW	*Mean number of moth catches	Temperature (ºC)		Relative humidity (%)		Wind speed (km/hr.)	Sunshine (hrs.)	Rainfall (mm)	Evaporation (mm)
			Max	Min	Morning	Evening				
09-10-2017	41	0.00	29.94	21.83	88.17	67.02	0.48	4.67	5.51	2.31
16-10-2017	42	0.00	29.71	21.00	81.31	65.01	0.90	4.19	4.29	3.60
23-10-2017	43	0.25	31.06	20.17	81.66	52.85	0.75	8.79	0.00	4.16
30-10-2017	44	0.20	29.63	19.74	85.19	58.09	1.19	7.23	0.00	4.04
07-11-2017	45	1.10	28.46	19.17	88.69	67.95	1.14	5.46	0.29	2.63
13-11-2017	46	3.00	30.29	17.86	86.15	55.07	0.51	6.27	0.00	3.60
21-11-2017	47	3.50	31.80	19.46	82.41	52.46	0.87	6.33	0.00	3.91
27-11-2017	48	4.25	28.89	18.89	84.66	64.21	1.47	5.00	0.00	3.11
03-12-2017	49	2.50	30.54	18.60	83.77	57.39	0.85	7.10	0.00	4.03
10-12-2017	50	1.85	31.17	15.77	87.66	51.93	0.66	8.30	0.00	3.93
18-12-2017	51	3.25	29.49	13.80	83.16	46.10	1.20	8.71	0.00	4.09
24-12-2017	52	1.00	29.26	13.11	84.60	41.22	1.12	9.34	0.00	4.09
03-01-2018	1	2.10	31.37	14.46	84.14	45.86	0.49	8.91	0.00	4.34
11-01-2018	2	0.95	30.49	15.23	84.29	46.14	1.06	8.77	0.00	4.66
17-01-2018	3	0.50	31.46	13.86	81.57	44.29	1.15	9.16	0.00	4.41
23-01-2018	4	0.00	30.34	13.57	83.43	41.57	0.65	9.14	0.00	5.04
01-02-2018	5	0.25	30.29	12.77	88.14	39.86	1.10	9.79	0.00	5.57
07-02-2018	6	0.80	31.86	17.00	81.29	39.43	0.81	7.04	0.17	4.54
15-02-2018	7	0.25	32.49	16.80	80.71	37.43	1.03	8.41	0.00	5.31
22-02-2018	8	0.00	33.29	14.00	74.00	32.43	1.18	9.86	0.00	6.93
Max.		4.25	32.49	20.17	88.69	67.95	1.47	9.79	0.29	5.57
Min.		0.00	28.46	12.77	80.71	37.43	0.49	5.00	0.00	2.63
Mean		1.51	30.52	16.49	84.21	49.52	0.94	7.87	0.03	4.20

*SMW- Standard Meteorological Weeks, * mean number of moths for seven days in four traps*

Table 37. Relationship between C. *punctiferalis* moth catches in castor field with abiotic factors at ZAHRS, Babbur farm, Hiryur, 2017

Variables		Temperature (ºC)		Relative humidity (%)		Wind speed (km/h)	Sunshine (hrs.)	Rainfall (mm)	Evaporation (mm)
		Max.	Min.	Morning	Afternoon				
Mean moth catches		-0.212 NS	0.550*	0.490*	0.464*	0.059 NS	-0.579*	-.0141 NS	-0.571*
Temperature (ºC)	**Max. (X_1)**	1	-0.037 NS	-0.611**	-0.567*	-0.499*	0.307 NS	-0.261 NS	0.571*
	Min. (X_2)		1	-0.057 NS	0.726**	0.022 NS	-0.762**	0.264 NS	-0.570*
Relative humidity (%)	**Morning (X_3)**			1	0.447 NS	0.041 NS	-0.183 NS	0.265 NS	-.0347 NS
	Afternoon (X_4)				1	0.198 NS	-0.783**	0.319 NS	-0.876**
Wind speed (km/h) (X_5)						1	-0.174	.098 NS	-0.169
Sunshine (hrs.) (X_6)							1	-0.456 NS	0.769**
Rainfall (mm) (X_7)								1	-0.433 NS
Evaporation (mm) (X_8)									1

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

Multiple linear regression equation:

N=17, $\boldsymbol{R^2}$**=0.780**, Y (Moth catches) = 15.420 + 0.229(X_1) -0.350(X_2) - 0.029(X_3) - 0.004(X_4) - 0.197(X_5) - 0.925(X_6) - 10.284(X_7) -1.124(X_8)

4.2 Mass rearing *C. punctiferalis* and *C. sahyadriensis*

The borer, *C. punctiferalis* was reared on different diets in laboratory (Plate 17). On Diet-A, the insect completed the life cycle in 40.12 days. On Diet-B, which comprised cardamom plant powder as a constituent, mortality of larva was recorded in second instar. So, the insect could not complete life cycle on Diet-B. On Diet-C, the insect completed the life cycle in 44.74 days and speciality of this diet was that no plant powder was incorporated in the diet. Diet-D consisted of natural host plant-castor. The insect took just over 45.13 days to complete the life cycle. The Analysis of Variance and Bonferroni tests revealed significant statistical differences in the time required for growth and development of the insect (Table 38 and Fig. 9). The data revealed that Diet-A consisting castor as constituent plant was most suited for insect growth and development. Diet-B was unsuitable for the growth and development of *C. punctiferalis*, as cardamom may not be in the innate host range of the castor borer, *C. punctiferalis*.

Host plants affect the development, survival, and fecundity of herbivorous insects. Shorter development times and higher reproduction rates of insects on a host indicate greater suitability of a host plant (Saeed *et al.*, 2010). Honda *et al.* (1979) were the first to report from Japan on meridic diet for *C. punctiferalis.* Utsumi *et al.* (1990) also proposed meridic diet for *C. punctiferalis* but both diets had lower yields of insects. However, these attempts provided useful baseline data for developing a well-defined diet for the shoot and fruit borer, *C. punctiferalis*. Ambanna (2014) found that larval period of *C. punctiferalis* on cardamom leaf semi-synthetic diet, plain diet, maize diet, castor diet and natural diet was 30.42±1.10, 26.10±1.2, 23.6±0.80, 23.5±0.70 and 21.50±0.95 days, respectively and pupation lasted for 11.6±0.40, 10.8±0.40, 10.6±0.35, 10.4±0.40 and 9.6±0.20 days, respectively and adult longevity on an average with mean of 9.0±1.0, 8.5±0.5, 8.7±0.540, 8.9±0.3 and 8.8±0.4 days, respectively. Doddabasappa *et al.* (2014) reported that the egg incubation period in laboratory was maximum 2.90 days. The moths laid eggs on compact spiny type castor and followed by 2.67, 2.70 days was in *Conogethes* reared on spineless spike castor type.

Detailed observations were recorded on the effect of meridic diets on reproductive traits of the borer. Since, the insect did not survive on Diet-B, the observation on

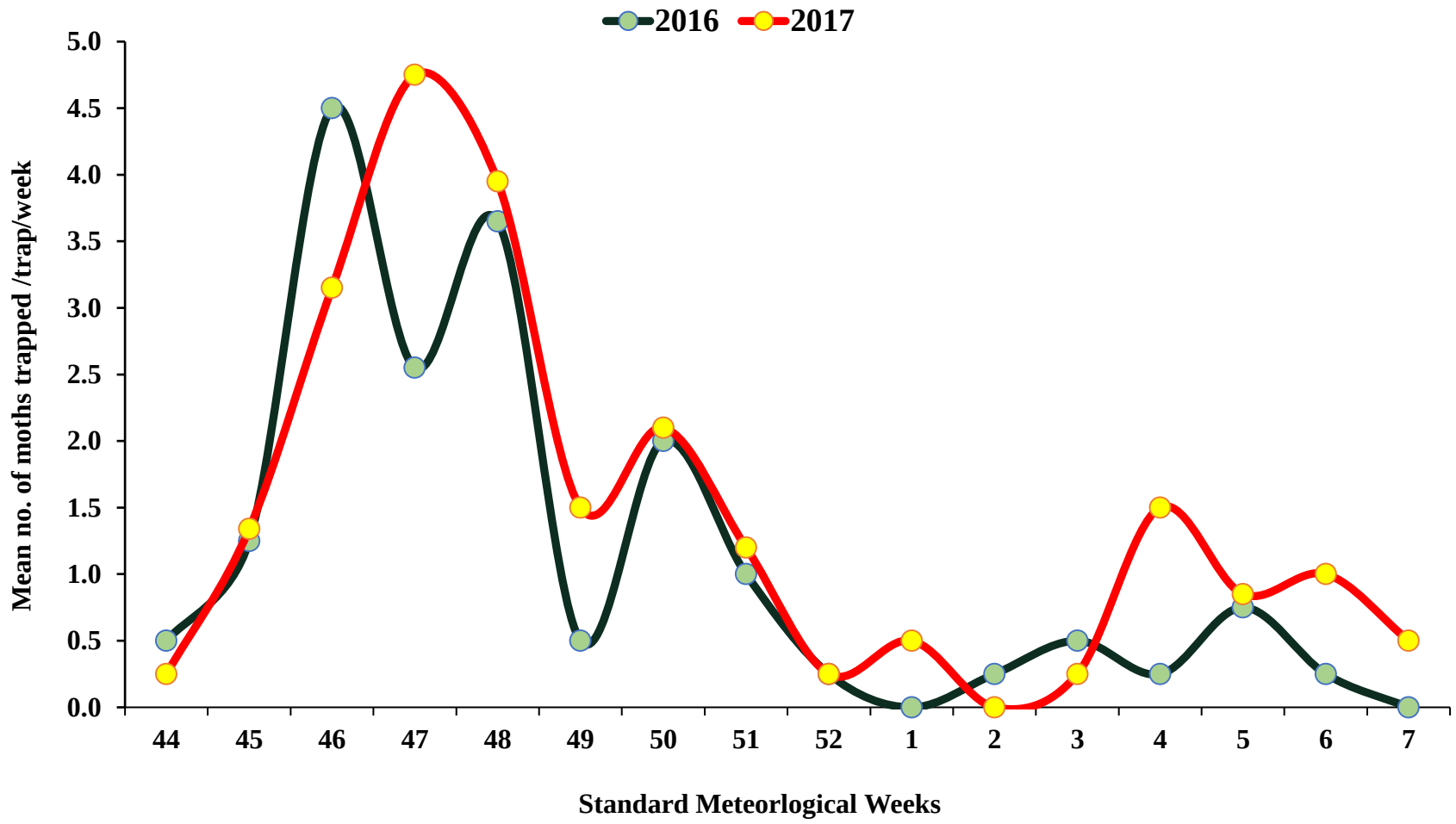

Fig. 7. Mean number of moth catches in yellow delta trap at GKVK, Bengaluru, during 2016 to 2017 (n=5)

Traps were placed in castor field on 4th November 2016 to 15th February 2017, and on 2nd November 2017 to 16th February 2018 and checked at weekly interval, pheromone lured rubber septa were replaced after 60 days of placement.

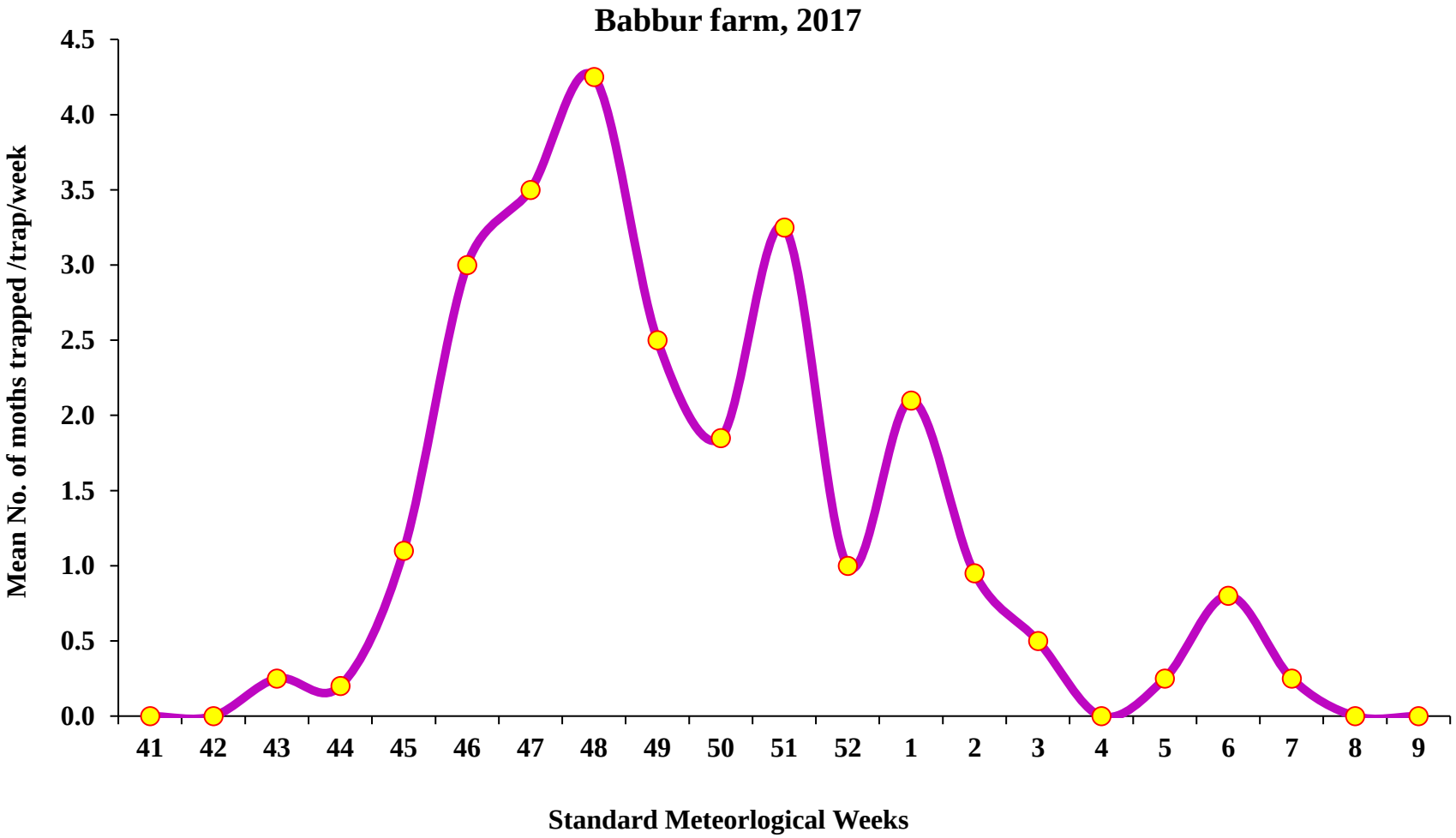

Fig. 8. Mean number of moth catches in yellow delta trap at ZAHRS, Babbur farm, Hiryur, during 2017 (n=5)

Traps were placed in castor field on 9th October 2017 and checked weekly until 27th February 2018, pheromone lured rubber septa were replaced after 60 days of placement.

reproductive traits of insect could not be recorded. The Analysis of Variance and Bonferroni tests did not reveal statistical differences ($p<0.05$) in premating, pre-oviposition, oviposition and post-ovipositional periods when fed on a particular diet. The time required for premating, pre-oviposition, oviposition and post-ovipositional periods varied from nearly 2-3 days (Table 39 and Fig. 9).

Mean pre-ovipositional and ovipositional periods of castor borer was 1.41±0.14 and 2.76±0.30 days, respectively (Ganesha *et al.,* 2013). Pre-oviposition period was 2.43±0.1, 2.45±0.4 and 2.23±0.1 days on spineless spike, compact spiny and spiny loose type of castor, respectively. There were non-significant differences among the castor types (Doddabasappa *et al.,* 2014). The pre-oviposition and ovipositional period on an average was found to be 1.61±0.40 and 5.5±0.50 days, respectively (Ambanna 2014). The pre-oviposition, oviposition and post-oviposition periods were 1.39± 0.50, 4.35± 0.57 and 2.26± 0.62 days, respectively (Umbarkar and Patel, 2014).

Since *C. punctiferalis* and *C. sahyadriensis* are two distinct and different species incorporation of castor plant powder inhibited the growth and development of *C. sahyadriensis*. Similarly incorporation of cardamom plant powder in the diet inhibited growth and development of *C. punctiferalis*. Therefore, the insect did not complete the life cycle on artificial diet with non-host plant material as a constituent of the diet. Doddabasappa (2012) also concluded from the studies that larvae reared on cardamom did not establish and complete the life cycle on castor and vice-versa. Results of the present investigations coroborate with the findings of earlier studies and it is concluded and continued that *C. punctiferalis* and *C. sahyadriensis* require artificial diets with respective plant powders incorporated into the diet. Artificial diets with the same constituents were not suitable for the mass multiplication of both the species of *Conogethes*.

The borer, *C. sahyadriensis* was reared on different diets in laboratory (Plate 17). On Diet-B, the insect completed the life cycle in 38.66 days. On Diet-A, which comprised castor plant as a constituent, mortality of larva was recorded in third/fourth instar. So, the insect could not complete life cycle on Diet-A. On Diet-C, the insect completed the life cycle in 45.59 days and speciality of this diet was that no plant powder was incorporated

Table 38. Biology of *C. punctiferalis* on different diets in laboratory

Developmental Stages		Duration (days)			
		Diet-A	**Diet-B**	**Diet-C**	**Diet-D**
Egg		3.12±0.04^{c}	4.27± 0.07^{a}	3.74± 0.06^{b}	3.6± 0.07^{b}
Larva	I instar	2.36±0.13^{ab}	2.11±0.76^{b}	3.73±0.09^{a}	3.80±0.15^{a}
	II instar	3.56±0.06^{b}	0.85±0.08^{c}	4.00±0.07^{a}	3.69±0.11^{b}
	III instar	3.87±0.14^{a}	0.51±0.07^{b}	3.96±0.13^{a}	4.05±0.06^{a}
	IV instar	3.59±0.07^{b}	0.40 ±0.09^{c}	3.75±0.08^{ab}	3.91 ±0.12^{a}
	V instar	3.57±0.04^{b}	0.40±0.09^{c}	3.71±0.09^{ab}	3.80±0.05^{a}
Total Larval Period		16.95±0.44^{b}	4.27±1.09^{c}	19.15±0.46^{ab}	19.25±0.49^{a}
Pre pupa		2.15±0.04^{b}	0.32±0.09 ^{c}	2.39±0.06^{a}	2.41±0.07^{a}
Pupa	Male	8.4±0.10^{b}	-	9.35±0.04^{a}	9.40±0.10^{a}
	Female	9.2±0.08^{b}	-	10.45±0.11^{a}	10.31±0.13^{a}
Adult longevity	Male	8.39±0.08^{b}	-	8.69±0.15^{ab}	9.11±0.29^{a}
	Female	9.80±0.10^{c}	-	10.43±0.07^{b}	10.91±0.11^{a}
Total developmental period		40.12±0.7^{b}	8.86±1.16^{c}	44.74±0.77^{ab}	45.13±0.95^{a}

Diets A-C are meridic diets and Diet D was natural food (Control); Means ± standard error (n=5) and means followed by different letters in the same row are significantly different at p<0.05 (analysis of variance; Bonferroni test).

Table 39. Effect of meridic diets on reproductive traits of *C. punctiferalis*

Reproductive events	Duration (Days)			
	Diet-A	**Diet-B**	**Diet-C**	**Diet-D**
Pre-mating	2.28±0.04^{b}	-	2.54±0.05^{ab}	2.68±0.09^{a}
Pre-oviposition	1.78±0.07^{b}	-	1.98±0.14^{b}	2.28±0.08^{a}
Oviposition	2.46±0.07^{b}	-	3.02±0.11^{a}	3.22±0.11^{a}
Post-oviposition	2.26±0.05^{b}	-	2.48±0.05^{a}	2.60±0.04^{a}

Diets A-C are meridic diets and Diet D was natural food; Means ±Standard error (n=5) within a row and followed by the same letter are not significantly different at p<0.05 (analysis of variance; Bonferroni test).

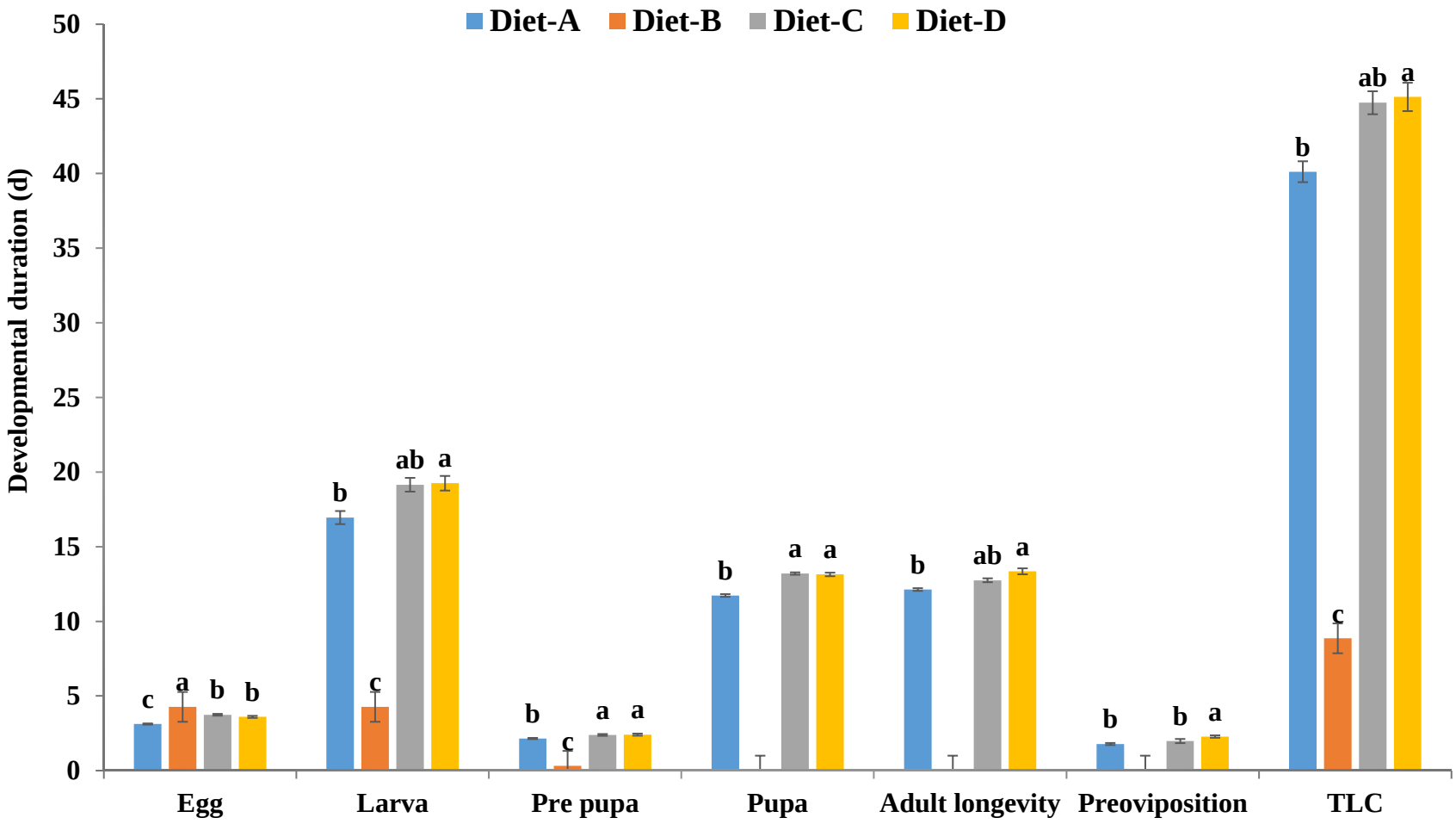

Fig. 9. Life cycle of life stages of *C. punctiferalis* fed on different diets

TLC- total life cycle; Bars represent means ±standard error; significant differences among four diets are indicated by different lowercase letters on each bar (Bonferroni test, P<0.05).

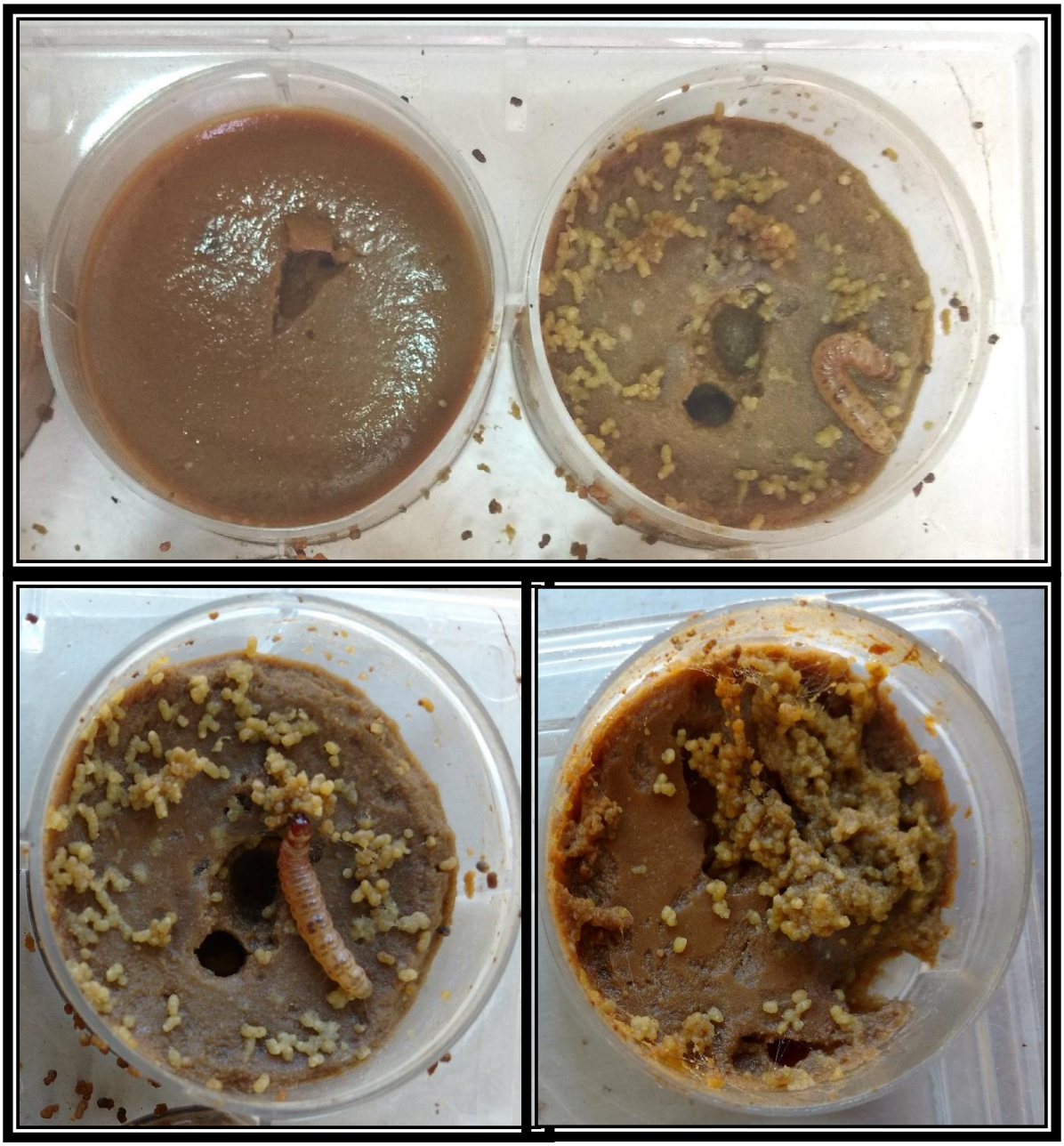

Plate 17. Larvae feeding on artificial diet with excretal pellets

in the diet. Diet-D consisted of natural host plant-cardamom. The insect took just over 46.53 days to complete the life cycle. The Analysis of Variance and Bonferroni tests revealed significant statistical differences (($p<0.05$) in the time required for growth and development of the insect (Table 40 and Fig. 10). The data revealed that Diet-B consisting cardamom as constituent plant was the most suited for insect growth and development. Diet-A was unsuitable for the growth and development of *C. sahyadriensis.*

Currently, Ballal *et al.* (1995) successfully used an artificial diet across several seasons for rearing *Chilo partellus* Swinhoe at the National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru and was mass reared systematically up to five generations. The diet was compounded with chickpea flour (100g), yeast tablets (10g), maize leaf powder (10g), casein (30g), ascorbic acid (3g), sorbic acid (1g), salt mixture no.2 (1.5g), multi vitex capsules (2 Nos.), methyl parahydroxy benzoate (2g), streptomycin sulphate (0.25), agar-agar (10g) formalin (2ml) and distilled water (700ml). At the end of three generations of rearing on this diet the larval survival was 75%. Also, the weight of male pupa (0.055g), female pupa (0.188g) and mean fecundity per female (232.33) were recorded. The diet could be stored at $5^0 \pm 1^0$C even up to 10 days without affecting quality of the insects. The cost of rearing a hundred pupae on the above diet was Rs. 18. These studies revealed that incorporation of host plant in the diet enhanced the growth and development of other crambid species like *C. partellus* and the Asiatic rice borer, *Chilo suppressalis* (Walker) reared on the artificial diet showed better performance with shorter developmental stage, similar larval survival rate and fecundity and heavier pupae compared with that fed on rice plants and fresh water bamboo. A positive correlation was recorded between number of eggs laid per female and number of generations reared on the artificial diet. Larval development time tended to be shortened with successive rearing on the artificial diet (Han *et al*., 2012). This suggested that the incorporation of host plant as a constituent of the artificial diet not only served as a token stimulus but may be of nutritional value. The artificial diet without host plant constituent delayed the completion of the life cycle of the *Conogethes* moths compared to artificial diet with host plant as a constituent.

Li *et al.* (2015) found that the highest concentration of chestnut meal contained diets resulted in enhanced survival rate, shortened developmental duration, increased pupal

weight, and increased number of eggs produced by *Conogethes* females. Total life cycle of the cardamom borer on the Malabar and Vazhuka cardamom types lasted for 35.74 and 41.18 days, respectively (Doddabasappa *et al.*, 2014). Kasareddy (2017) studied the biology of *C. sahyadriensis* on cardamom, recording the egg, larval and prepupa duration as 4.00±0.20, 26.70±2.30 and 4.25±0.71 days, respectively. Total development period of male and female moths was maximum (42.45±5.38 and 44.05±5.24 days, respectively) when reared on turmeric compared to on cardamom (37.80±1.91 and 39.25±1.75 days, respectively) and on ginger (40.10±1.37 and 42.50±3.50 days, respectively).

Detailed observations were recorded on the effect of meridic diets on reproductive traits of the borer, *C. sahyadriensis.* Since, the insect did not survive on Diet-A, the observations on reproductive traits of the insect were not recorded. The Analysis of Variance and Bonferroni tests did not reveal statistical differences ($p<0.05$) in premating, pre-oviposition, oviposition and post-ovipositional periods when fed on a particular diet. The time required for premating, pre-oviposition, oviposition and post-ovipositional periods varied from nearly 2-2.70 days (Table 41 and Fig. 10).

Doddabasappa *et al.* (2014) found that the pre-oviposition period was 5.51±0.2, 4.66±0.2, 5.16±0.3 days on Malabar, Mysore, Vazhuka types of cardamom, respectively. Kasareddy (2017) observed that the pre-oviposition, oviposition and post-ovipositional periods varied from nearly 2-3 days on cardamom.

The data on the pupal weight, adult longevity, fecundity and egg hatch when *C. punctiferalis* was reared on four diets revealed statistical significant differences ($p<0.05$) in the parameters studied (Table 42). Pupation (91.50%), female and male pupal weight (61.63 and 57.61mg, respectively) (Fig. 11), adult emergence (96.50%) fecundity (29.28) and egg hatch rate (91.50%) were the maximum when the borer fed on Diet-A. Obviously, observations pertaining to these parameters were not recorded on Diet-B. Diet-C was the least preferred diet for the insect as pupation (70%), female and male pupal weight (58.52 and 53.60mg, respectively) (Fig. 11), adult emergence (78.60%), fecundity (22.64 eggs per female) (Fig. 11) and egg hatch rate (72.40%) were the least (Table 42).

Table 40. Biology of *C. sahyadriensis* on different diets in laboratory

Developmental Stages		Duration (days)			
		Diet-A	**Diet-B**	**Diet-C**	**Diet-D**
Egg		4.92±0.12^{a}	3.25± 0.09^{b}	3.86± 0.22^{b}	3.94± 0.15^{c}
Larva	I instar	3.19±0.18^{b}	2.45±0.19^{c}	3.81±0.05^{a}	3.94±0.11^{a}
	II instar	0.51±0.11^{c}	3.28±0.05^{b}	4.07±0.07^{a}	3.87±0.12^{a}
	III instar	0.48±0.20^{b}	3.70±0.17^{a}	3.96±0.13^{a}	4.10±0.07^{a}
	IV instar	0.36±0.35^{a}	4.13±0.14^{ab}	4.97±0.04^{b}	4.77±0.07^{c}
	V instar	-	3.74±0.04^{b}	4.31±0.21^{a}	4.46±0.24^{a}
Total Larval Period		4.54±0.84^{c}	17.30±0.59^{b}	21.12±0.50^{a}	21.14±0.6^{a}
Pre pupa		-	2.49± 0.15^{b}	3.13± 0.15^{a}	3.35± 0.11^{a}
Pupa	Male	-	6.72± 0.17^{b}	8.22± 0.06^{a}	8.38± 0.11^{a}
	Female	-	7.95± 0.29^{b}	9.05± 0.25^{a}	9.36± 0.10^{a}
Adult longevity	Male	-	7.69± 0.20^{b}	8.45± 0.12^{a}	8.63± 0.07^{a}
	Female	-	8.86± 0.24^{b}	9.22± 0.20^{a}	9.82± 0.06^{a}
Total developmental period		9.46±0.96^{c}	38.66±1.28^{b}	45.59±1.18^{a}	46.53±1.05^{a}

Diets A-C are meridic diets and Diet D was natural food (Control); Means ± standard error (n=5) and means followed by different letters in the same row are significantly different at p<0.05 (analysis of variance; Bonferroni test).

Table 41. Effect of meridic diets on reproductive traits of *C. sahyadriensis*

Reproductive events	Duration (Days)			
	Diet-A	**Diet-B**	**Diet-C**	**Diet-D**
Pre-mating	-	2.33± 0.06^{b}	2.74± 0.22^{a}	2.91± 0.11^{a}
Pre-oviposition	-	1.30± 0.13^{b}	1.52± 0.16^{b}	2.17± 0.14^{a}
Oviposition	-	2.48± 0.04^{a}	2.38± 0.27^{b}	2.62± 0.19^{a}
Post-oviposition	-	2.14± 0.07^{b}	2.42± 0.12^{a}	2.56± 0.08^{a}

Diets A-C are meridic diets and Diet D was natural food; Means ±Standard error (n=5) within a row and followed by the same letter are not significantly different at p<0.05 (Analysis of Variance; Bonferroni test).

Accordingly, the artificial diet evaluated by Ambanna (2014) for rearing *C. punctiferalis* reported that minimum pupal weight (0.37 mg) on plain semi-synthetic diet was significantly lower than natural and castor diet. Li *et al.* (2015) reported mean pupal weights of 73.6 mg for males and 77.3 mg for females and a fecundity rate of 97.9 eggs / female. When reared on chestnut and maize, *C. punctiferalis* were shown to have a shorter preadult developmental time, higher preadult survival rate, shorter total pre-oviposition period, longer adult longevity, higher fecundity, and greater pupa weight compared to the other three diets (Chen *et al.*, 2018). Du *et al.* (2015) studied life cycle of *C. punctiferalis* on four diets with different rates in the amounts of chestnut meal, corn meal, and soybean meal. The diet containing 30 g chestnut meal, 70 g corn meal, and 70 g soybean meal per 700-ml diet yielded a larval survival rate of 94.5%, a generation developmental time of 42.4 d, mean pupal weights of 73.6 mg for males and 77.3 mg for females, and an adult fecundity rate of 97.9 eggs/female. Performance on this diet compared favorably with rearing on fresh corn. Li *et al.* (2015) found that adult females developed from the larvae fed on chestnut and maize laid significantly more eggs (average 141.8 and 133.5 eggs per female, respectively) than those fed on the other host plants *viz.*, chestnut, maize, plum, apple, pear and peach.

The data on the pupal weight, adult longevity, fecundity and egg hatch when *C. sahyadriensis* was reared on four diets revealed statistical significant differences ($p<0.05$) in the parameters studied (Table 43). Female and male pupal weight (81.20 and 62.81mg, respectively) (Fig. 12), pupation (92.46%), adult emergence (95.80%), fecundity (26.70 eggs per female) and egg hatch rate (90.86%) were the maximum when the borer fed on Diet-B. Obviously, observations pertaining to these parameters could not be recorded on Diet-A. Diet-C was the least preferred diet for the insect as pupation (75.70%), adult emergence (75.30%), fecundity (19.50 eggs per female) (Fig. 13) and egg hatch rate (71.10%) were the least (Table 43).

Fecundity of *C. sahyadriensis* gravid moths ranged from 70-180 eggs per female with a mean of 46.25±3.9, 66.25±0.8, 59.33±4.0 eggs, while viability ranged from 80.00 to 88.55 per cent with an average of 41.50±5.4, 91.40±6.2, 84.80±4.6 per cent on Malabar, Mysore and Vazhuka types of cardamom, respectively (Doddabasappa *et al.*, 2014).

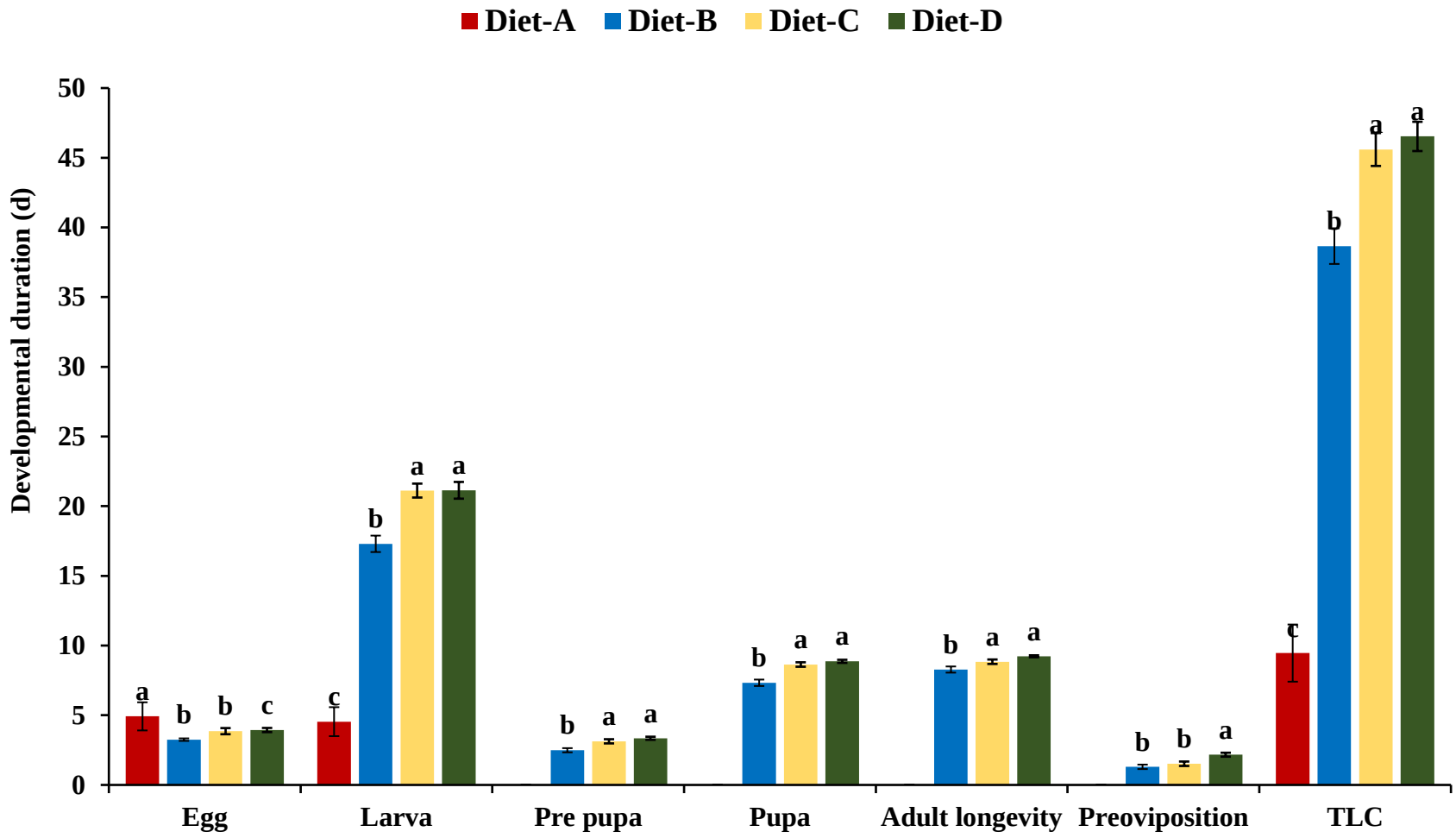

Fig. 10. Life cycle of *C. sahyadriensis* fed on different diets

TLC- total life cycle; Bars represent means ±standard error; significant differences among four diets are indicated by different lowercase letters on each bar (Bonferroni test, P<0.05).

Observations on survival rates of *C. punctiferalis* on different diets were recorded in laboratory. On four diets 25 larvae each were released and observations on number of pupae, number of adults and growth index were recorded. Higher survival rate of larva (95.20%) and pupa (88.66%), maximum number of pupae (23.80), adults (21.10) and growth index (5.62) were recorded on Diet-A compared to other diets. Diet-C proved the least suitable. Diet-D recorded moderate numbers of pupal survival, adults and growth index. There were statistically significant differences ($p<0.05$) with respect to the parameters when *C. punctiferalis* was reared on four diets in laboratory (Table 44 and Fig. 14).

Survival rates of *C. punctiferalis* were significantly impacted by diet. Percentage of survival of larvae from egg hatch to pupation was 94.5% on AD-I, 80.0% on the fresh corn control, 26.5% on AD-III, 25.6% on AD-IV, and 18.0% on AD-II. Percentage of survival from egg hatch to adult emergence was 78.5% on AD-I, 71.4% on the fresh corn control, 20.9% on AD-III, 20.6% on AD-IV, and 8.0% on AD-II. The hatch rate of eggs from those adults was the highest for the AD-I diet (67.7%) and the lowest for the AD-III (29.8%) and AD-II (26.9%) diets (Du *et al.*, 2015). Li et al. (2014) observed that the survival and reproduction of *C. punctiferalis* were impacted by the choice of the host plant material incorporated in meridic diets. The survival rates of C. *punctiferalis* reared n chestnut and maize were significantly higher those in the other three treatments reflecting the higher pre-adult survival rates on these hosts (Chen *et al.*, 2018)

Observations on survival rates of *C. sahyadriensis* on different diets were recorded in laboratory. On four diets 30 larvae each were released and observations on number of pupae, number of adults and growth index were recorded. The highest survival rate of larva (91.66%) and pupa (92.72%), maximum number of pupae (27.50), adults (25.50) and growth index (5.30) were recorded on Diet-B compared to other diets. Diet-C proved the least suitable. Diet-D recorded moderate numbers of pupal, larval survival, adults and growth index. There were statistical significant differences ($p<0.05$) with respect to these parameters when *C. sahyadriensis* was reared on four diets in laboratory (Table 45 and Fig. 14).

Further observations on life table parameters of *C. punctiferalis* on meridic diets and natural food were recorded on four diets. Again, Diet-A proved the best for *C. punctiferalis* as the net reproductive rate (6.35), gross reproductive rate (10.11), intrinsic rate of increase (4.81), finite rate of increase (1.05) and mean generation time (38.47) were least favouring the Diet-A over other diets (Table 46).

Life-table parameters often vary with different environmental variables, host species, and myriad other factors (Atlihan *et al.,* 2017 and Özgökçe *et al.,* 2018). Li *et al.* (2015) reported that a generation developmental time for *C. punctiferalis* on artificial diet ranged from 42.4 d to 63.3 days. Du *et al.* (2015) reported that the mean generation time (*Td*) for the AD-I diet and the fresh corn control were statistically equal; both were statistically shorter than *Td* values of the AD-II, AD-III, and AD-IV diets. The intrinsic rate of increase (r) values for *C. punctiferalis* larvae fed on the AD-I diet (0.074) and fresh corn (0.073) was higher than those observed with the AD-IV (0.037), the AD-III (0.008), and the AD-II (0.031) diets. Cohorts fed on fresh corn or the AD-I diet thus had a higher level of fitness than cohorts fed on the other artificial diets. Campos *et al.* (2017) suggested that the net reproductive rate (R_o) of *Condylorrhiza vestigialis* (Guenée) reared on the artificial diet was 401.70, and on the natural diet was 151.22. The demographic parameters, including the net reproductive rate (R_0), intrinsic rate of increase (r), and finite rate (λ) values on chestnut and maize were significantly higher than the other three treatments viz., sunflower seeds, hawthorn fruits, and apple fruits (Chen *et al.,* 2018).

Observations on life table parameters of *C. sahyadriensis* on meridic diets and natural food were recorded on four diets. Again, Diet-B proved the best for *C. sahyadriensis* as the net reproductive rate (7.75), gross reproductive rate (11.58), intrinsic rate of increase (5.32), finite rate of increase (1.05) and mean generation time (38.51) were favouring the diet Diet-B over other diets (Table 47).

Table 42. Effect of meridic diets on pupal weight, adult longevity, fecundity and egg hatch of *C. punctiferalis*

Diet	Pupation (%)	Pupal Weight (mg)		Adult Emergence (%)	Fecundity	F_1hatch rate (%)
		Female	Male			
Diet-A	91.50±2.55[a]	61.63± 0.26[a]	57.61± 0.59[a]	96.50±2.00[a]	29.28±0.29[a]	91.50±1.00[a]
Diet-B	-	-	-	-	-	-
Diet-C	70.00±4.18[b]	58.52± 0.35[c]	53.60± 0.88[c]	78.60±3.74[b]	22.64±0.37[c]	72.40±5.61[b]
Diet-D	79.80±2.92[b]	59.59± 0.49[b]	55.50± 0.62[b]	80.50±3.54[b]	26.44±0.23[b]	79.00±1.87[b]

Diets A-C are meridic diets and Diet D was natural food (Control); Means ±Standard error (n=5) within a column and followed by the same letter are not significantly different at p<0.05 (analysis of variance; Bonferroni test).

Table 43. Effect of meridic diets on pupal weight, adult longevity, fecundity and egg hatch of *C. sahyadriensis*

Diet	Pupation (%)	Pupal Weight (mg)		Adult Emergence (%)	Fecundity	F_1hatch rate (%)
		Female	Male			
Diet-A	-	-	-	-	-	-
Diet-B	92.46±1.82[a]	81.20± 0.98[a]	62.81± 0.99[a]	95.80±1.24[a]	26.70± 0.66[a]	90.86±1.56[a]
Diet-C	75.70±4.27 [b]	70.72± 1.77[b]	56.40± 2.60[b]	75.30±2.70 [c]	19.50± 0.35[c]	71.10±3.37[c]
Diet-D	81.20±2.63[b]	72.39± 1.33[b]	58.35± 1.17[ab]	83.75±2.73[b]	21.30± 0.37[b]	80.20±2.45[b]

Diets A-C are meridic diets and Diet-D was natural food; Means ±Standard error (n=5) within a column and followed by the same letter are not significantly different at p<0.05 (analysis of variance; Bonferroni test).

Table 44. Survival rates of *C. punctiferalis* on different diets in laboratory

Diet	No. of larvae used	No. of pupae	Larval survival (%)	No. of Adults	Growth index	Survival (%) of pupa	Total Survival (%)
Diet-A	25	23.80±0.20^{a}	95.20±0.80^{a}	21.10±1.20^{a}	5.62	88.66±2.30^{a}	84.40±2.50^{a}
Diet-B	25	2.20±1.50^{c}	8.80±4.10^{c}	-	2.06	-	8.80±4.10^{c}
Diet-C	25	19.40±1.40^{b}	77.60±3.60^{b}	15.60±1.20^{b}	4.05	80.41±4.60^{b}	62.40±3.20^{b}
Diet-D	25	20.10±1.20^{b}	80.40±2.80^{b}	17.40±1.40^{b}	4.18	86.57±2.60^{ab}	69.60±3.35^{b}

Diets A-C are meridic diets and Diet D was natural food (Control); Means ±Standard error (n=5) within a column and followed by the same letter are not significantly different at p<0.05 (Analysis of Variance; Bonferroni test).

Table 45. Survival rates of *C. sahyadriensis* on different diets in laboratory

Diet	No. of larvae used	No. of pupae	Larval survival (%)	No. of Adults	Growth Index	Pupal Survival (%)	Total Survival (%)
Diet-A	30	4.80±2.50^{c}	16.00±3.60^{c}	-	3.52	-	16.00±3.60^{c}
Diet-B	30	27.50±0.35^{a}	91.66±0.24^{a}	25.50±1.40^{a}	5.30	92.72±2.50^{a}	85.00±1.95^{a}
Diet-C	30	21.60±1.80^{b}	72.00±2.40^{b}	18.50±2.15^{b}	3.41	85.64±3.6^{b}	61.66±3.50^{b}
Diet-D	30	23.40±1.40^{b}	78.00±1.25^{b}	20.50±1.50^{b}	3.69	87.60±2.3^{b}	68.33±2.85^{b}

Diets A-C are meridic diets and Diet D was natural food; Means ±Standard error (n=5) within a column and followed by the same letter are not significantly different at p<0.05 (Analysis of Variance; Bonferroni test).

Table 46. Life table parameters of *C. punctiferalis* on meridic and natural food

Diet	R_0	*GRR*	*r*	λ	*T*(d)
Diet-A	6.35±0.01^{a}	10.11±0.08^{a}	4.81±0.02^{a}	1.05±0.10^{a}	38.47±0.05^{d}
Diet-B	-0.31±0.45^{d}	1.56±0.92^{d}	-2.34±1.05^{d}	0.98±0.58^{d}	50.02±1.56^{a}
Diet-C	3.09±0.30^{c}	6.22±0.26^{bc}	2.61±0.50^{c}	1.03±0.42^{bc}	43.18±0.30^{b}
Diet-D	4.58±0.10^{b}	7.09±0.23^{b}	3.65±0.12^{b}	1.04±0.35^{c}	41.71±0.18^{c}

Diets A-C are meridic diets and Diet D was natural food (Control); Net reproductive rate (R_0); gross reproductive rate (GRR); intrinsic rate of increase (r); finite rate of increase (λ); mean generation time (Td); Means ± Standard error and Means followed by different letters in the columns are significantly different by paired bootstrap test based on the CI of difference. Standard errors were estimated by 1,000,000 bootstrap resampling.

Table 47. Life table parameters of *C. sahyadriensis* on meridic and natural food

Diet	R_0	*GRR*	*r*	λ	*T*(d)
Diet-A	0.42±0.51^{d}	1.82±1.04^{d}	-0.02±1.20^{d}	0.98±0.56^{d}	50.28±2.15^{a}
Diet-B	7.75±0.25^{a}	11.58±0.13^{a}	5.32±0.08^{a}	1.05±0.20^{a}	38.51±0.06^{d}
Diet-C	4.12±0.10^{c}	7.89±0.16^{c}	3.25±0.45^{c}	1.03±0.35^{c}	43.52±0.45^{b}
Diet-D	5.92±0.15^{b}	9.64±0.34^{b}	4.24±0.22^{b}	1.04±0.40^{b}	41.88±0.28^{c}

Diets A-C are meridic diets and Diet D was natural food; Net reproductive rate (R_0); gross reproductive rate (GRR); intrinsic rate of increase (r); finite rate of increase (λ); mean generation time (Td); Means ± Standard error and Means followed by different letters in the same column are significantly different by paired bootstrap test based on the CI of difference. Standard errors were estimated by 1,000,000 bootstrap resampling.

The morphometric data of shoot and capsule borer reared on castor are as given in Table 48. The average length and breadth of eggs of *C. punctiferalis* was 0.64± 0.09 and 0.37± 0.25 mm, respectively. Average length of 1st instar, 2nd instar, 3rd instar,4th instar and last stage of larva were 1.36 ±0.15, 3.20 ± 0.21, 5.60 ± 0.25, 9.95 ±0.42 and 16.25 ± 1.56 mm, respectively. Average length of pre-pupa, male and female pupa is about 14.35 ± 1.30, 9.65 ± 1.05 and 10.58 ± 0.62 mm, respectively (Table 48). Adult is yellow, forewing length 10~12.50 mm, dotted with 26-29 black dots and the hind wings were also brownish yellow, length of 11~13mm and with 28-30 black dots (Plate 18).

The average length and width of the eggs of castor borer were 0.59 and 0.39 mm, respectively. Studies of Ganesha (2011) conducted in Bengaluru revealed that egg length and width ranged from 0.59 to 0.67 mm with a mean of 0.63±0.01 mm and from 0.45 to 0.51 mm with a mean of 0.46±0.02 mm, respectively on castor capsules. Azam and Ali (1965) studied the morphology of larva of *C. punctiferalis* with special reference to chaetotaxy collected from castor bean (*Ricinus communis* L.). The full-grown larva was stout, reddish brown in color, with numerous short tubercles on its body and measured 25-30 mm in length (Singh *et al*., 2002). There is a clear difference in the size, shape and weight of the male and female pupa. Female pupae were bigger (17.81 x 6.29 mm with 0.127 gm in weight). Male pupa measured 14.30 x 4.26 mm with 0.108 gm weight (Thyagaraj, 2003).

Yathish (2012) from Nagpur, Central India, who reported that when *Conogethes* reared on castor the pre pupal length varied from 13.2 to 13.8 mm with an average of 13.4 mm and width range from 2.4 to 2.7 mm with an average of 2.5 mm. Pupal length varied from 11.2 to 11.8 mm with an average of 11.48 mm and width varied from 2.7 to 2.9 mm with an average of 2.78 mm. Ganesha (2011) studied and reported that the pre-pupal length varied from 13.20-13.80 mm with an average of 13.42 ± 0.24 mm and width ranged from 2.45-2.75 mm with an average of 2.59 ± 0.11 mm. Pupal length varied from 11.10-12.00 mm with an average of 11.47 ± 0.30 mm and width varied from 2.60-2.85 mm with an average of 2.72 ± 0.08 mm.

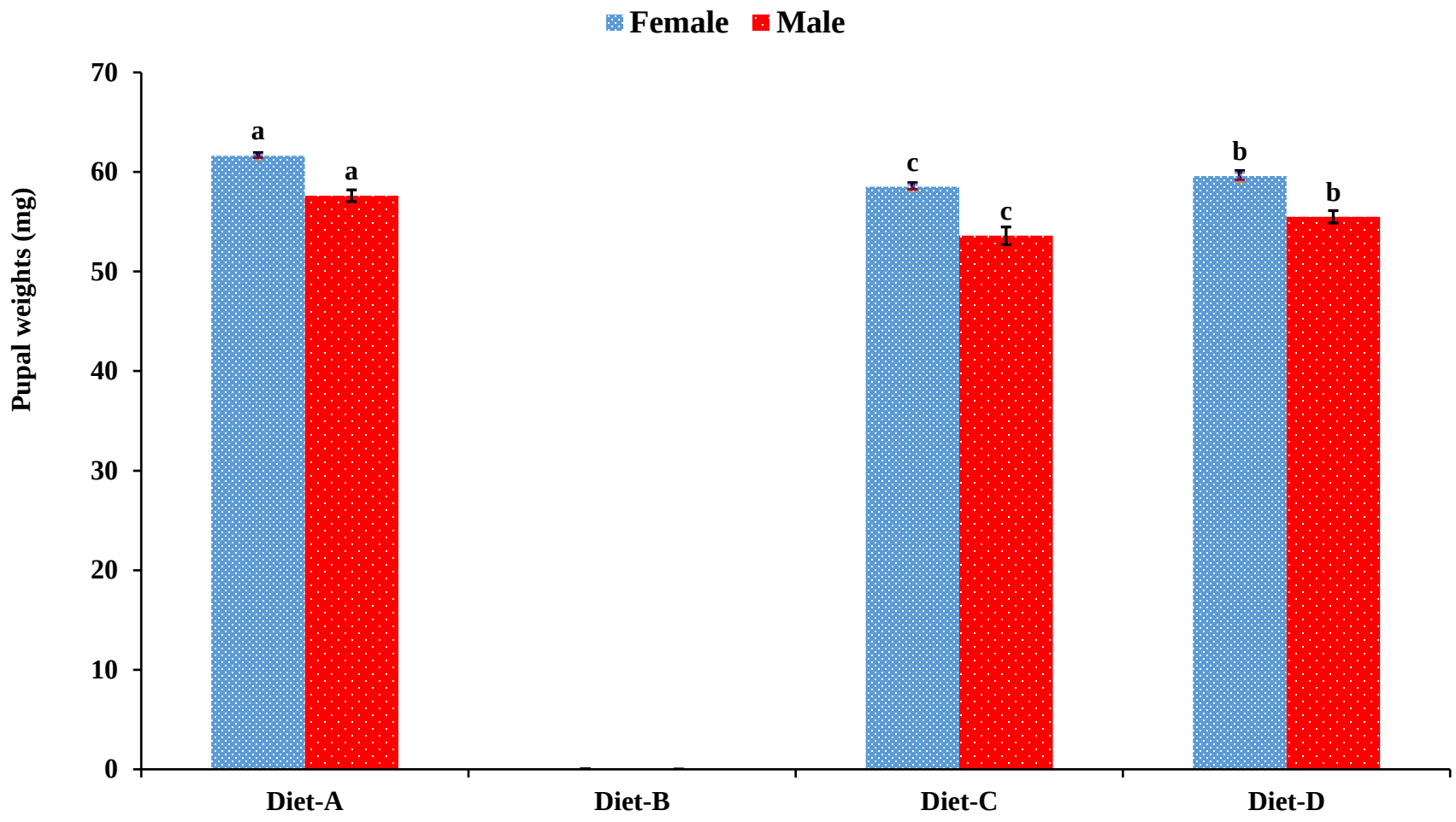

Fig. 11. Pupal weights (mg) of *C. punctiferalis* fed on different diets

Bars present means ±standard error; significant differences among four diets are indicated by different lowercase letters on each bar (Bonferroni test, P<0.05).

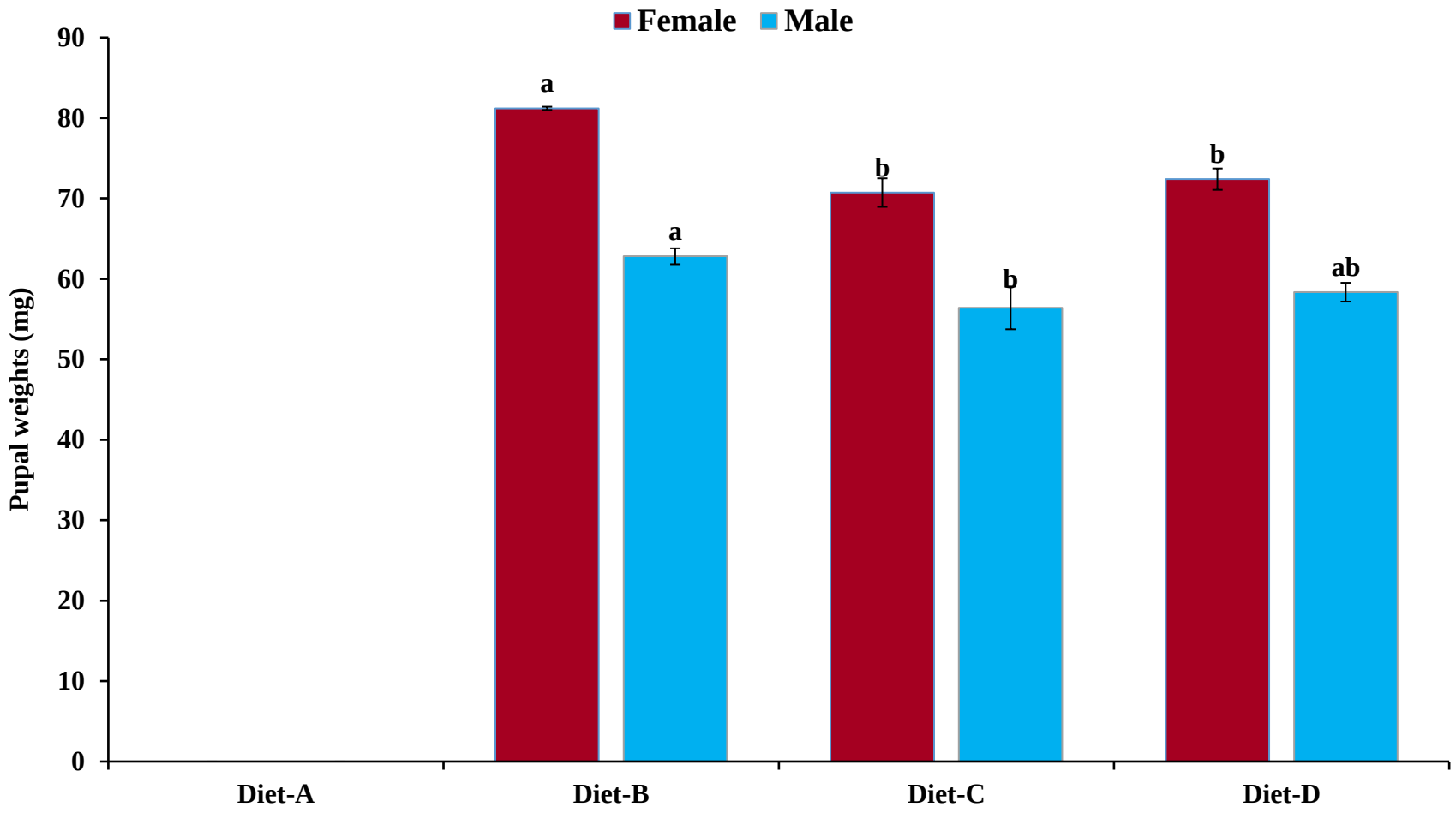

Fig.12. Pupal weights (mg) of *C. sahyadriensis* fed on different diets.

Bars present means ±standard error; significant differences among four diets are indicated by different lowercase letters on each bar (Bonferroni test, P<0.05).

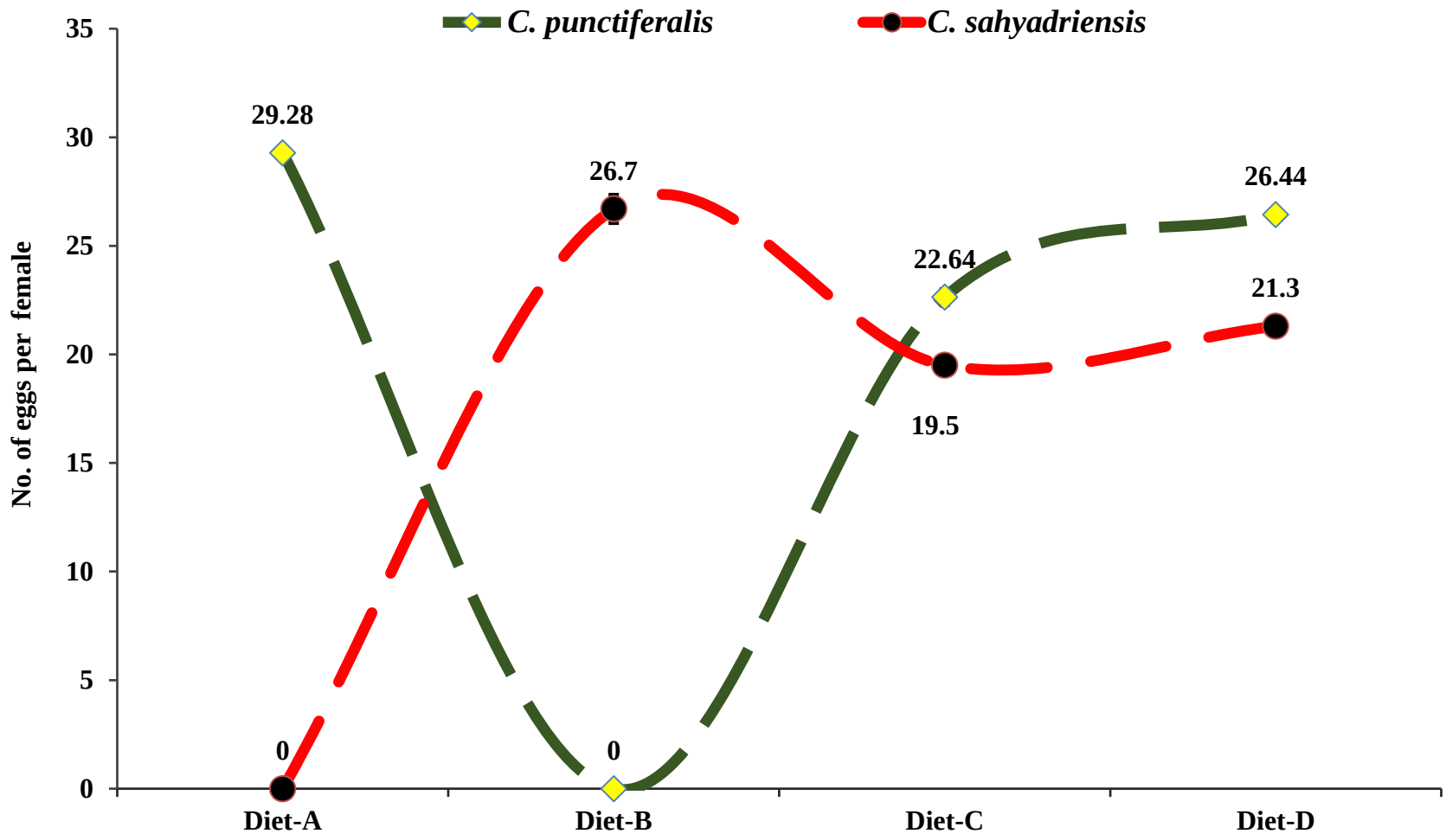

Fig. 13. Fecundity of *C. punctiferalis* and *C. sahyadriensis* fed on different diets.

Bars represent means ±standard error (Bonferroni test, P<0.05).

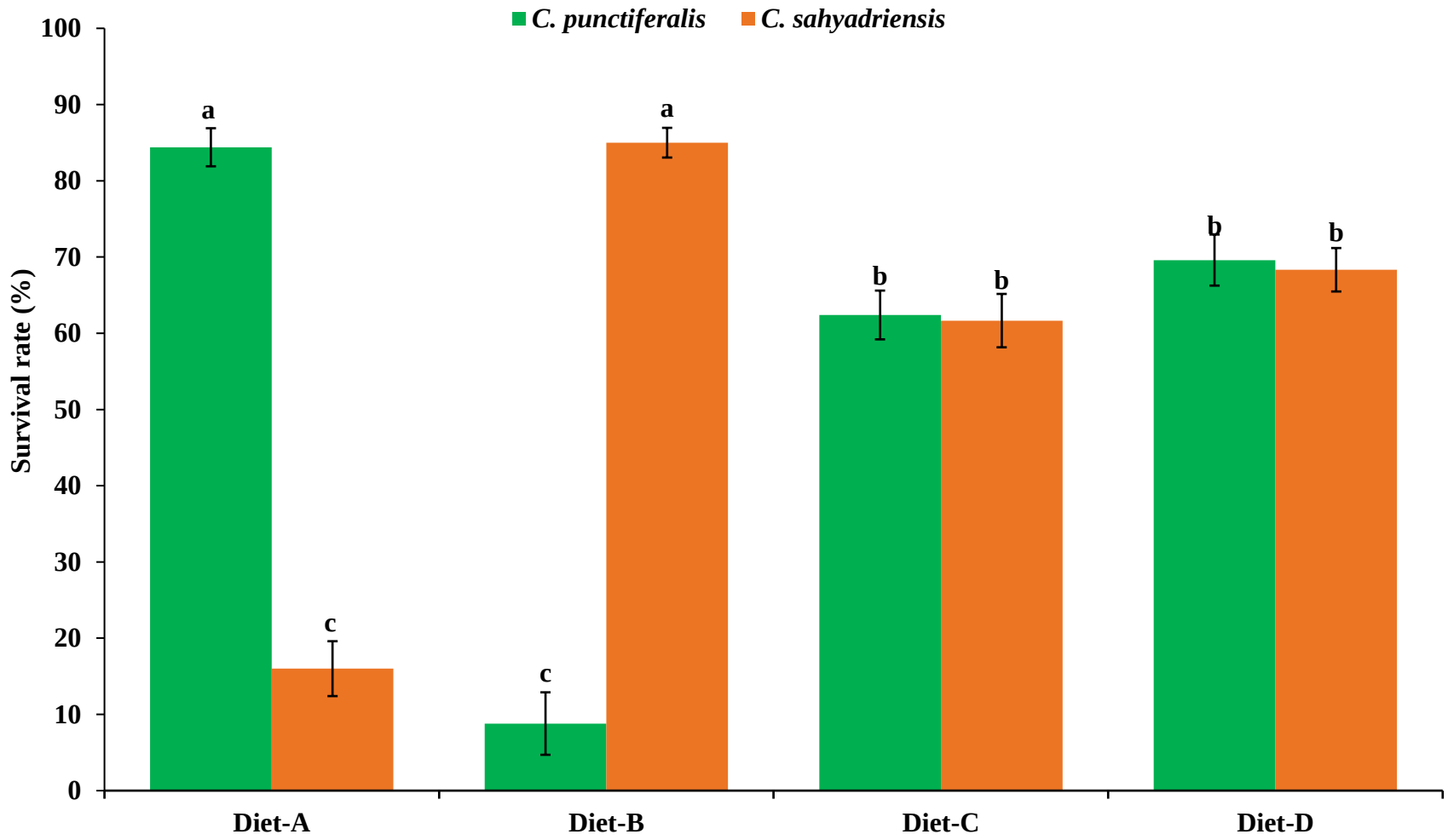

Fig. 14. Survival rate of *C. punctiferalis* and *C. sahyadriensis* fed on diets

Bars represent means ±standard error; significant differences among four diets are indicated by different lowercase letters on each bar (Bonferroni test, P<0.05).

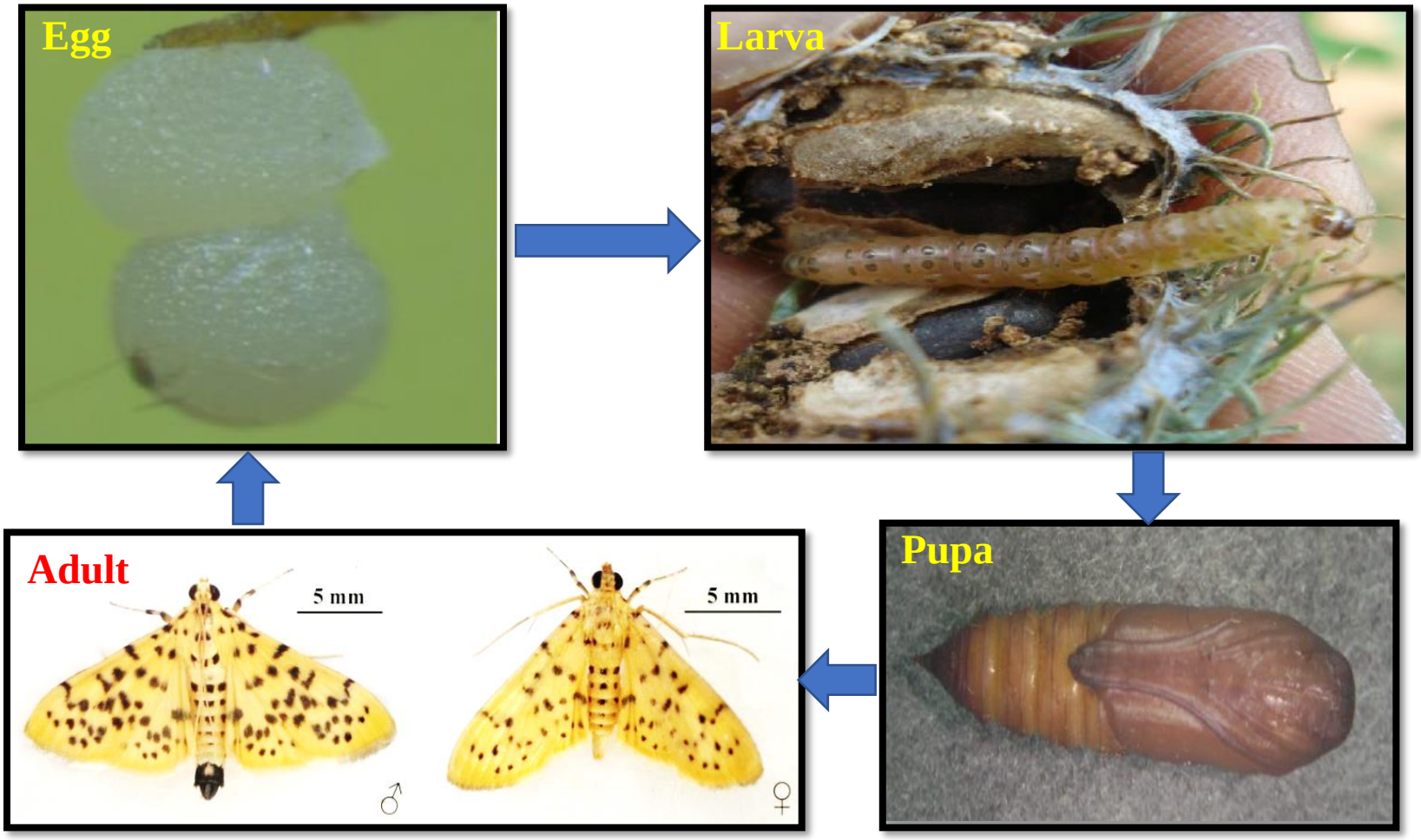

Plate 18. Life stages of Castor Borer, *C. punctiferalis*

Ai *et al.* (2014) observed that the length of newly hatched larva of castor borer is about 2.05 mm, grey white and somewhat reddish; along with the instars increasing, the colour is darkened gradually. Average length of the 2nd instar, 3rd instar, 4th instar and last stage larva were 5.13 mm, 9.28 mm, 13.49 mm and 20.67 mm, respectively. Abdominal legs were with biordinal, penellipse crochets. Average length of pupa is about 10.50 mm, soft and yellowish at early stage, then turns orange, and dark brown near eclosion. Adult is yellow, forewing length 10.00~11.50 mm, dotted with 25~28 leopard black spots. Kuang *et al.* (2009) recorded that the mean weight, length and width of pupae were 75.1+or-1.8 mg, 13.42+or-0.13 mm and 3.39+or-0.04 mm, respectively

The morphometric data of shoot and capsule borer when reared on cardamom are as given in Table 49. The average length and breadth of egg of *C. sahyadriensis* was 0.68± 0.34 and 0.42± 0.02 mm, respectively. Average length of 1st instar, 2nd instar, 3rd instar,4th instar and last stage of larva were 2.8 ±0.25, 4.66±0.50, 9.70±0.65, 16.35±0.40 and 24.30 ± 1.05 mm, respectively. Average length of pre-pupa, male and female pupa is about 15.55± 0.80, 15.55 ± 0.13 and 17.60 ± 1.20mm, respectively (Table 49). Adult is yellow, forewing length 12~13 mm, dotted with 25-28 black dots and the hind wings were also brownish yellow, length of 13~14.50 mm and with 28-30 black dots (Plate 19).

Kasareddy (2017) observed the eggs of *C. sahyadriensis* laid on cardamom having on an average length was 0.62±0.05 mm and the average breadth was 0.39±0.01 mm. Average length of the 1st instar, 2nd instar, 3rd instar, 4th instar and last stage larva were 2.76±0.06 mm, 4.45±0.12 mm, 9.68±0.82 mm, 16.80±0.30 mm and 24.65±0.68 mm, respectively. Average of the prepupa and pupa were about 15.45±1.15 mm and 15.45±1.15 mm, respectively. The average length of male and female moths was 12.40±0.26 mm and 14.50±1.26 mm, respectively.

Rashmi (2014) reported that the average length and breadth of egg measured in the laboratory was 0.66± 0.05 days and 0.41 ± 0.02 mm, respectively. The average length and breadth of first instar (2.57 ± 0.08 mm and 0.40 ± 0.01mm, respectively), 2nd instar (4.70 ± 0.42 mm and 0.75 ± 0.05 mm, respectively), 3rd instar (9.65 ± 0.41 mm and 1.39 ± 0.15 mm, respectively), 4th instar (15.80 ± 0.78 mm and 2.48 ± 0.38 mm, respectively) and 5th

instar (24.10 ± 1.19 mm and 2.90 ± 0.48 mm, respectively). Average width of second, third, fourth and fifth instars was 0.32 ± 0.01 mm, 0.51 ± 0.03 mm 0.82 ± 0.06 mm and 1.26 ± 0.06 mm, respectively.

Ovipositional preference of gravid *C. punctiferalis* moths are shown in Table 50. Cotton plug and castor capsules were preferred the most for egg laying. On an average, female laid 29 eggs on castor capsules compared to cotton plug which recorded on an average 35.18 eggs per plug (Table 50 and Fig. 15). These findings corroborate with studies of Kumar *et al.* (2016) on different substrates for oviposition by female moths revealed that highest mean per cent oviposition (41.97%) were recorded on the cotton plug, followed by young castor capsules (30.75%), water swab (9.03%) and the least mean per cent oviposition was recorded on the honey swab (2.83%) dipped in 10 per cent honey solution.

Ganesha *et al.* (2013) found that the gravid female moths deposited eggs singly on capsules and cotton wads. Stanley *et al.* (2009) reported that the female moths laid eggs singly or in groups in between the warts or just below the style on the ovary of the flowers and on the developing capsule to up the half mature stage. In the absence of red light even though moths could lay eggs they were mostly sterile. So the red light was found essential for *Conogethes* moths to lay fertile eggs.

Ovipositional preference of gravid *C. sahyadriensis* moths are shown in Table 51. Cotton plug and cardamom capsules were preferred the most for egg laying. An average female laid 33.27 eggs on cardamom capsules compared to cotton plug which recorded on an average 31.78 eggs per plug (Table 51 and Fig. 15).

A small laboratory experiment was also conducted, and it was found that gravid *C. punctiferalis* moths preferred castor twigs (46.5 eggs) over castor capsules (15.5 eggs), leaves (5 eggs), petiole (3 eggs), main stem (1 egg) and peduncle (nil) (Table 52). The experiment was extended in laboratory with different materials as ovipositional substrates. The data is presented in Table 53. Cotton plug (15.29, mean number of eggs/female) was the most preferred substrate for *C. punctiferalis* in laboratory compared to castor twigs, capsules, black cotton cloth, honey swab and water swab (Table 53 and Fig. 16).

Patel and Gangrade (1971) reported that the eggs were laid in groups of 1 - 6 on the inflorescences and capsules by *C. punctiferalis* moths and the egg stage lasted from four days at 30ºC to 11 days at 20ºC. Kumar *et al.* (2016) recorded that ovipositional preference on different plant parts by gravid females resulted in maximum number of eggs (41-48 / female) was recorded on castor twigs and then the inflorescence/capsules (9-11 eggs/female) were preferred by the moths for oviposition. The development of the *C. punctiferalis* was investigated in laboratory on apple by Kodoi and Kaneda (1990), the number of eggs laid on caged apple averaged 0.25 at 26oc and 70 per cent relative humidity.

EAG response and multiple choice oviposition through field surveys and behavioral test Xu *et al*. (2001) studied that the effects of volatiles from Nongda No.1 chestnut (NC) and Heyuan oil chestnut (HC) on the host-selection behavior of adult *C. punctiferalis*. For both NC and HC, the EAG responses of female and male moths to capsule volatiles were higher than those to leaf volatiles. The number of eggs laid by female moths was much greater on NC capsules than on NC leaves and on HC capsules and leaves.

A small laboratory experiment was also conducted, and it was found that gravid *C. sahyadriensis* moths preferred cardamom tender unopened leaves (39.5 eggs) over cardamom capsules (19.5 eggs), shoots (6 eggs) and opened leaves (nil) (Table 54). The experiment was extended in laboratory with different materials as ovipositional substrates. The data is presented in Table 55. Cardamom capsules (11.14, mean number of eggs/female) was the most preferred substrate for *C. sahyadriensis* in laboratory compared to shoots, cotton plug, black cotton cloth and water swab (Table 55 and Fig. 17).

These findings are in accordance with Rashmi (2014) who reported that *C. sahyadriensis* moth eggs were laid singly sticking to the sides of veins and midrib of unopened leaves of cardamom. Devasahayam *et al.* (2010) reported that adult moths laid eggs on the tender unopened leaves of ginger. On cardamom, moths laid eggs singly on the top of the leaf axils of young pseudostems, rarely two larvae are found in a pseudostem. This kind of egg laying habit probably is to avoid larval competition for food within the same pseudostem (Thyagaraj, 2003).

Table 48. Morphometrics of life stages of castor shoot and capsule borer, *C. punctiferalis*

Instars		Length (mm)		Breadth (mm)		Head capsule width(mm)	
		Range	**Mean ± SD**	**Range**	**Mean ± SD**	**Range**	**Mean ± SD**
Egg		0.48 - 0.75	0.64± 0.09	0.30 - 0.49	0.37± 0.25	-	-
Larva	1st Instar	1.32 - 1.65	1.36 ± 0.15	0.25 - 0.55	0.28 ± 0.11	-	-
	2nd Instar	2.75 - 3.68	3.20 ± 0.21	0.65 - 0.85	0.70 ± 0.06	0.18 – 0.34	0.24±0.07
	3rd Instar	5.20 - 5.95	5.60 ± 0.25	1.10 - 1.35	1.25 ± 0.05	0.26 – 0. 48	0.35±0.05
	4th Instar	9.45 - 11.09	9.95 ± 0.42	2.10 - 2.30	2.20 ± 0.07	0.30 – 0.65	0.40±0.11
	5th Instar	12.5 - 18.75	16.25 ± 1.56	2.75 - 3.93	3.38 ± 0.21	0.42 – 0.95	0.68±0.21
Pre-pupa		12.25 - 15.05	14.35 ± 1.30	2.65 - 3.80	3.35 ± 0.15	-	-
Pupa	Male	7.75 - 10.90	9.65 ± 1.05	1.95 - 3.42	2.70 ± 0.45	-	-
	Female	9.15 - 11.85	10.58 ± 0.62	2.25 - 3.25	2.75 ± 0.24	-	-
Adult	Male	10.25 - 12.20	11.85 ± 0.35	19.50 - 25.20	22.82 ± 1.85*	-	-
	Female	9.75 - 12.80	11.50 ± 0.70	20.35 - 27.50	24.65 ± 1.50*	-	-

*Figures in boxes are Mean ± Standard Deviation (SD); n=20 larvae of each instar; * wing expansion*

Table 49. Morphometrics of life stages of shoot and capsule borer, *C. sahyadriensis*

Developmental Stages		Length (mm)	Breadth (mm)	Head capsule width(mm)
		Mean ± SD	Mean ± SD	Mean ± SD
Egg		0.68± 0.34	0.42± 0.02	-
Larva	1st Instar	2.85 ± 0.25	0.46 ± 0.08	-
	2nd Instar	4.66 ± 0.50	0.72 ± 0.01	0.25±0.03
	3rd Instar	9.70 ± 0.65	1.45 ± 0.02	0.44±0.08
	4th Instar	16.35 ± 0.40	2.52 ± 0.11	0.75±0.01
	5th Instar	24.30 ± 1.05	2.95 ± 0.30	1.15±0.25
Pre-pupa		15.55 ± 0.80	2.85± 0.12	-
Pupa	Male	15.55 ± 0.13	3.10 ± 0.15	-
	Female	17.60 ± 1.20	3.45 ± 0.25	-
Adult	Male	12.30 ± 0.45	25.40 ± 1.35*	-
	Female	14.70 ± 1.20	27.55 ± 1.60*	-

*Figures in boxes are Mean ± Standard Deviation (SD); N=25 larvae of each instar; * wing expansion*

Table 50. Ovipositional preference on selected substrates by gravid *C. punctiferalis* females

Days	Oviposition (%)				
	Castor capsules	Black cotton cloth	Cotton plug	Honey swab	Water swab
1	0.00	0.00	0.00	0.00	0.00
2	40.46	8.09	51.13	0.00	0.00
3	38.08	9.36	41.64	3.50	6.76
4	26.77	12.09	44.33	5.45	10.53
5	23.40	15.18	48.64	4.00	8.29
6	27.60	16.80	45.50	2.60	6.50
7	45.10	26.50	15.00	2.50	10.50
Mean	**28.77**	**12.58**	**35.18**	**2.58**	**6.08**

n=5 pairs of moths per replicates x 5 replicates.

Table 51. Ovipositional preference on select substrates by gravid *C. sahyadriensis* moths

Days	Oviposition (%)				
	Cardamom capsules	**Shoots**	**Cotton plug**	**Black cotton cloth**	**Water swab**
1	0.00	0.00	0.00	0.00	0.00
2	42.51	6.30	39.51	10.00	1.50
3	43.48	4.50	41.00	7.50	3.20
4	47.65	6.59	42.00	2.30	1.00
5	34.40	12.18	39.64	9.00	4.40
6	31.60	15.40	28.50	15.60	8.50
Mean	**33.27**	**7.50**	**31.78**	**7.40**	**3.10**

n=5 pairs of moths per replicates x 5 replicates.

Table 52. Ovipositional preference on different plant parts by gravid *C. punctiferalis* moths

Plant parts	Average number of eggs
Capsule/Inflorescence	15.5
Leaves (Fully opened)	5
Peduncle	0
Petiole	3
Main stem	1
Twigs (Unopened leaves)	46.5

n=5 pairs of moths per replicates x 5 replicates.

Table 53. Ovipositional pattern by gravid *C. punctiferalis* moths in laboratory

Days	Eggs laid (Number)				
	Castor capsules	Black cotton cloth	Cotton plug	Honey swab	Water swab
1	0.00	0.00	0.00	0.00	0.00
2	9.00	2.00	12.00	2.00	0.00
3	22.00	12.00	21.00	9.00	2.00
4	25.00	15.00	28.00	5.00	3.00
5	27.00	8.00	35.00	5.00	3.00
6	8.00	3.00	11.00	3.00	1.00
7	1.00	1.00	0.00	0.00	1.00
Total	92.00	41.00	107.00	24.00	10.00
Mean	13.14	5.86	15.29	3.43	1.43

n=5 pairs of moths per replicates x 5 replicates.

Table 54. Ovipositional preference on different plant parts by gravid *C. sahyadriensis* moths

Plant parts	Average number of eggs laid
Cardamom capsule/Inflorescence	19.5
Shoots	6
Leaves (Fully opened)	0
Tender unopened leaves	39.5

n=5 pairs of moths per replicates x 5 replicates.

Table 55. Ovipositional pattern by gravid *C. sahyadriensis* moths in laboratory

Days	Eggs laid (Number)				
	Cardamom capsules	Shoots	Cotton plug	Black cotton cloth	Water swab
1	0.00	0.00	0.00	0.00	0.00
2	8.00	3.00	8.00	1.00	0.00
3	20.00	8.00	23.00	6.00	3.00
4	26.00	6.00	18.00	4.00	1.00
5	17.00	7.00	13.00	6.00	2.00
6	5.00	3.00	7.00	1.00	5.00
7	2.00	0.00	0.00	1.00	0.00
Total	78.00	27.00	69.00	19.00	11.00
Mean	11.14	3.86	9.86	2.71	1.57

n=5 pairs of moths per replicates x 5 replicates.

4.2a Effect of plant factor on the development of *C. punctiferalis* and *C. sahyadriensis* in artificial diets

Efforts were made to study the effect of adding plant powder for growth and development of *C. punctiferalis* reared on four diets (Table 56). Diet-F_a contained 85g/ml of castor capsule powder and recorded the shortest period (38.24 days) to complete the life cycle compared to Diet E_a (40.12 days) which consisted higher quantity of castor capsule powder (100g/ml) (Table 56). The data on duration of egg, larva, prepupa, pupa and adult are as given in Table 56. Diet F_a proved better with higher survival rate of larva (93.45%), pupation (92.95%), adult emergence (96.75%) and fecundity (29.88 eggs per female) compared to other three diets (Table 57). Analysis of Variance and Bonferroni tests revealed statistical significant differences in the select life cycle parameters reared on four diets with varied quantity of plant constituents (Tables 56 and 57).

The chemical composition of host plants significantly affects survival, growth and reproduction of phytophagous insects (Bernays and Chapman, 1994). Growth, development and reproduction in insects are closely related to the quality and quantity of food consumed (Scriber and Stansky, 1981). Castor oil is a rich source of ricinoleic acid, which is a monounsaturated fatty acid. Castor oil also contains moderate amounts of other fatty acids like oleic acid, linoleic acid, linolenic acid, palmitic acid and stearic acid (https://en.wikipedia.org/wiki/Castor_oil).

Kalode *et al.* (1970) developed an artificial diet based on bean kernel for the rearing of *Sesamia inferens* (Walker). In Pakistan, pink stem borer was reared on plant factor based artificial diet using rice stem there by eliminating wheat germ or bean and the females obtained from this diet laid 194-400 eggs (Qureshi *et al.,* 1972). Each constituent in the diet had a role in the growth and development of *C. punctiferalis*. For instance, larvae of *C. punctiferalis* reared on chestnuts developed faster and had a higher survival rate than larvae reared on peach, cypress or persimmon (Choi *et al.,* 2006; Honda *et al.,* 1979). This indicated that chestnut is a useful ingredient in the meridic diet for *C. punctiferalis*. Accordingly, Li *et al.* (2014) from China reported that *C. punctiferalis* larvae reared on fresh corn and chestnut performed better than those reared on temperate fruits like peach, plum, pear and apple.

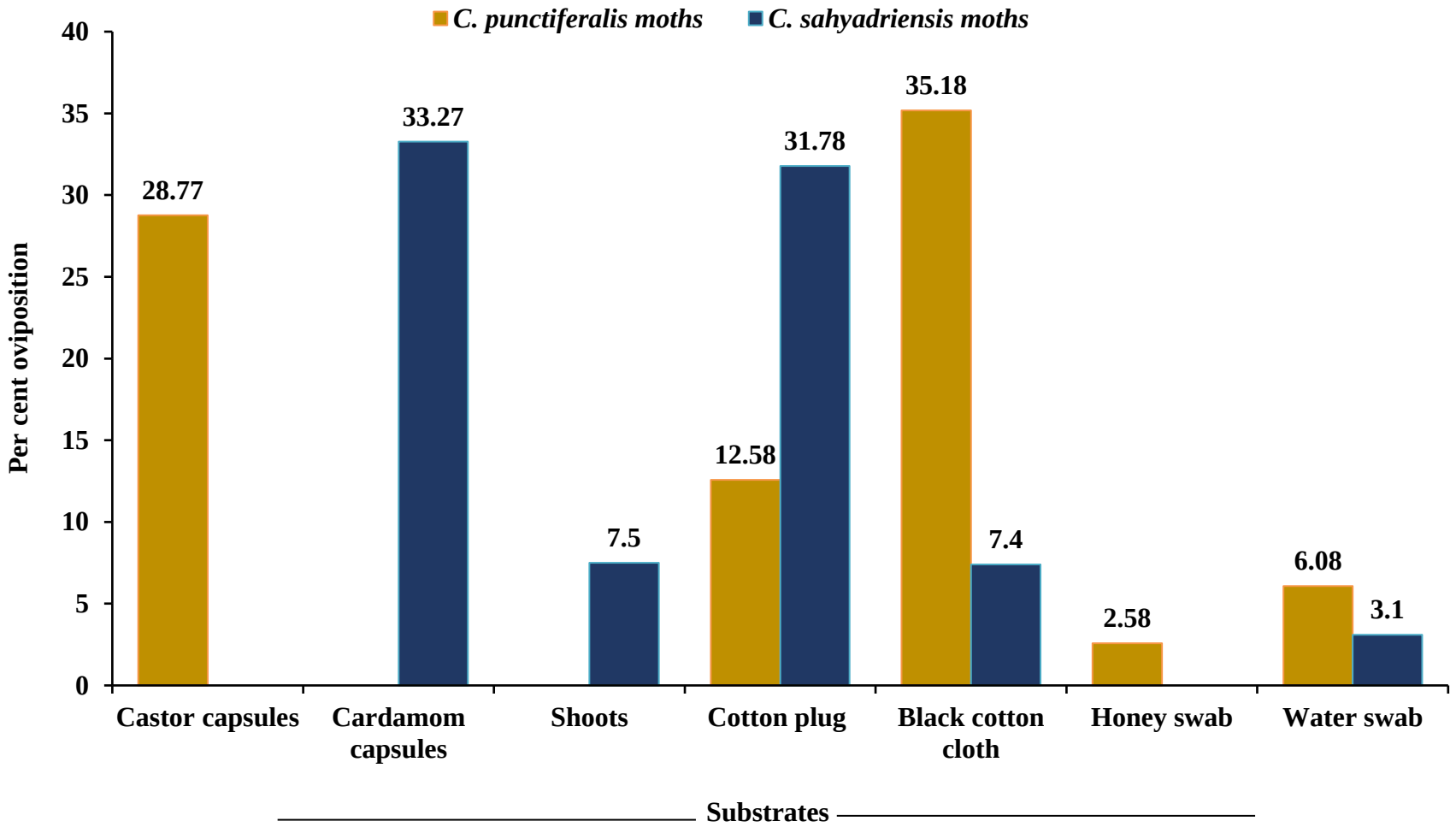

Fig. 15. Ovipositional preference on select substrates by gravid *C. punctiferalis* and *C. sahyadriensis* moths

n=5 pairs of moths per replicate x 5 replicates

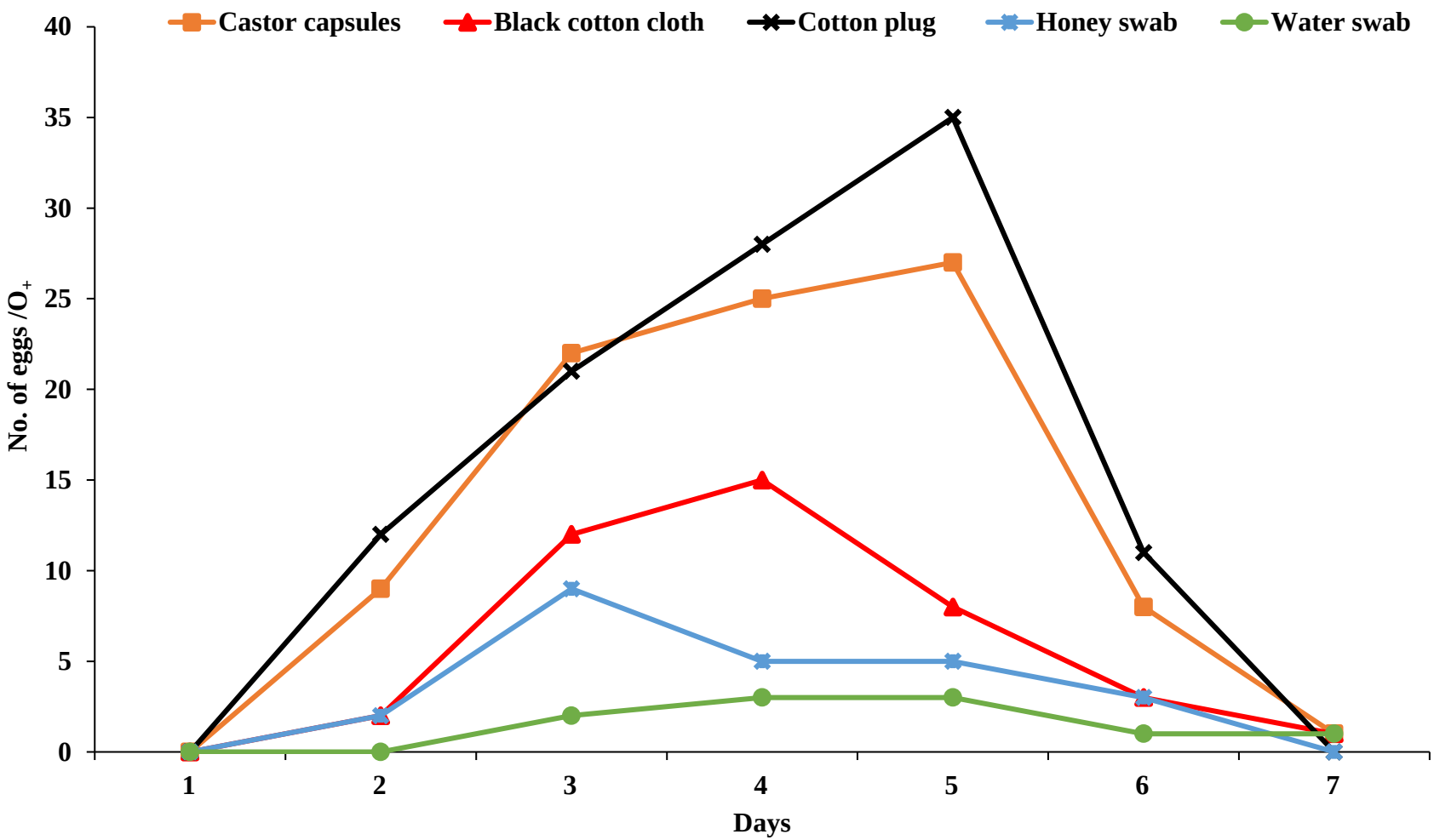

Fig. 16. Oviposition pattern by gravid *C. punctiferalis* moths

n=5 pairs of moths per replicate x 5 replicates

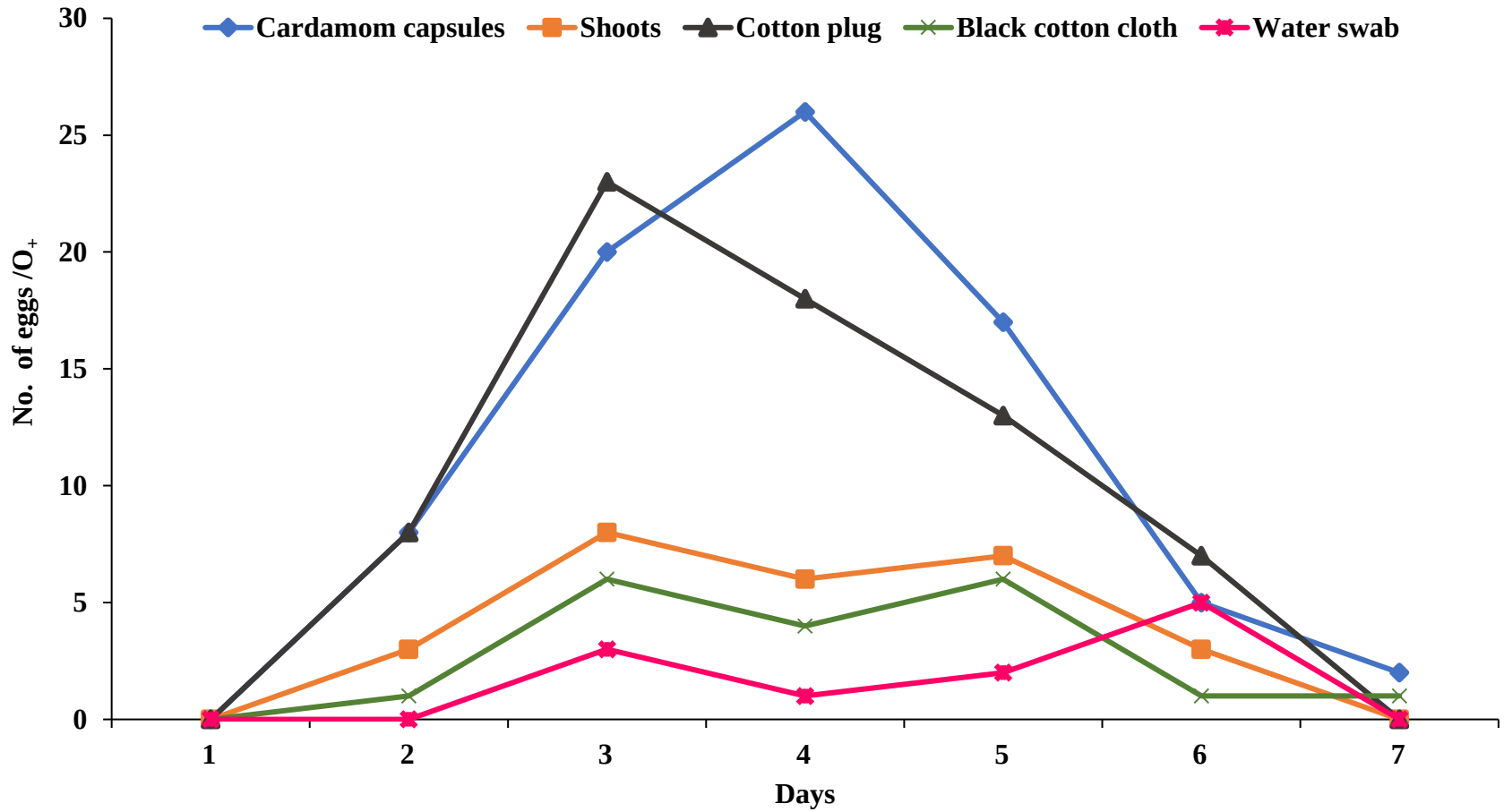

Fig. 17. Oviposition pattern by gravid *C. sahyadriensis* moths

n=5 pairs of moths per replicate x 5 replicates

Table 56. Effect of adding plant powder on growth and development of *C. punctiferalis* on diets (Diet E_a - H_a)

Developmental Stages		Duration (days)			
		Diet E_a	**Diet F_a**	**Diet G_a**	**Diet H_a**
Egg		3.12 ± 0.04^{c}	3.09 ± 0.25^{d}	3.45 ± 0.05^{b}	3.85 ± 0.15^{a}
Larva		16.72 ± 0.44^{c}	15.85 ± 0.18^{d}	17.50 ± 0.25^{b}	19.70 ± 1.05^{a}
Pre-pupa		2.15 ± 0.02^{bc}	2.05 ± 0.22^{c}	2.20 ± 0.12^{b}	2.80 ± 0.11^{a}
Pupa	**Male**	8.40 ± 0.10^{b}	7.80 ± 0.15^{d}	8.30 ± 0.45^{c}	9.50 ± 0.20^{a}
	Female	9.20 ± 0.08^{b}	8.95 ± 0.01^{c}	8.75 ± 0.08^{d}	10.15 ± 0.15^{a}
Adult longevity	**Male**	8.39 ± 0.08^{bc}	8.25 ± 0.13^{c}	8.45 ± 0.20^{b}	9.20 ± 0.25^{a}
	Female	9.80 ± 0.10^{b}	9.50 ± 0.11^{d}	9.65 ± 0.15^{c}	10.25 ± 0.35^{a}
Total developmental period		40.12 ± 0.70^{bc}	38.24 ± 0.85^{c}	40.73 ± 0.86^{c}	45.90 ± 1.68^{a}

Diets E_a -G_a contained varied quantities of plant powder; Diet H_a was without plant powder (Control); Means ± standard error (n=5) and means followed by different letters in the same row are significantly different at p<0.05 (Analysis of Variance; Bonferroni test).

Table 57. Effect of Plant factor on Pupal weight and fecundity of *C. punctiferalis* on diets (Diet E_a - H_a)

Diets	Larval survival (%)	Pupation (%)	Pupal weight (mg)		Adult emergence (%)	Fecundity
			Male	**Female**		
Diet E_a	91.35 ± 0.14^{b}	90.75 ± 2.25^{c}	59.25 ± 0.25^{ab}	62.75 ± 0.65^{a}	94.50 ± 1.20^{c}	29.10 ± 0.85^{ab}
Diet F_a	93.45 ± 0.26^{a}	92.95 ± 1.25^{a}	57.61 ± 0.59^{b}	61.64 ± 0.85^{b}	96.75 ± 2.10^{a}	29.88 ± 0.29^{a}
Diet G_a	90.50 ± 0.10^{c}	91.25 ± 2.15^{b}	59.40 ± 0.65^{a}	62.65 ± 0.70^{ab}	94.85 ± 2.25^{b}	28.88 ± 0.11^{b}
Diet H_a	88.70 ± 0.45^{d}	80.32 ± 0.85^{d}	46.52 ± 1.54^{c}	55.30 ± 0.85^{c}	82.65 ± 1.40^{d}	21.50 ± 0.65^{d}

Diets E_a -G_a contained varied quantities of plant powder; Diet H_a was without plant powder (Control); Means ± standard error (n=5) and means followed by different letters in the same columns are significantly different at p<0.05 (Analysis of Variance; Bonferroni test).

Efforts were made to study the effect of adding plant powder for growth and development of *C. sahyadriensis* reared on four diets (Table 58). Diet-J_a contained 85g/ml of cardamom capsule powder and recorded the shortest period (36.81 days) to complete the life cycle compared to Diet I_a (38.66 days) which consisted higher quantity of castor capsule powder (100g/ml) (Table 58). The data on duration of egg, larva, prepupa, pupa and adult are as given in Table 58. Diet J_a proved the best with the highest survival rate of larva (91.66%), pupation (92.46%), adult emergence (95.80%) and fecundity (26.70 eggs per female) compared to other three diets (Table 59). Analysis of Variance and Bonferroni tests reveal statistical significant differences ($p<0.05$) in the select life cycle parameters reared on four diets with varied quantity of plant constituents (Tables 58and 59). Continued feeding depends on the presence of feeding stimulants but not necessarily on the same ones in each stage. Phagostimulant compounds may be of nutritional value or may only provide token stimuli. Carbohydrates, proteins, amino acids, lipids, sterols, salts, vitamins, cellulose, agar, guanine monophosphate, terpenes and several organic aldehydes have shown phagostimulant properties for insects (Singh, 1977).

The most significant component of cardamom, as spice, is the volatile oil with its characteristic aroma, described generally as camphoryl, sweet, aromatic spicy. The cardamom oil has few mono- or sesquiterpene hydrocarbons and is predominantly made up of oxygenated compounds. While many of the identified compounds – alcohols, esters and aldehydes – are commonly found in many spice oils, the dominance of the ether, 1,8-cineole and the esters, α-terpinyl and linalyl acetates in the composition, make the cardamom volatiles a unique combination. The aroma differences in different sources of cardamom are attributed to the proportion of the esters and 1, 8-cineole (Wijesekar and Jayawardena, 1973; Korikanathimath *et al*., 1997). *Ostrinia nubilalis* (Hübner) larvae were stimulated mainly by glucose and to a lesser extent by fructose and sucrose (Beck, 1956). Cardamom is an excellent source of Vitamin C, Calcium, Magnesium, Potassium and Zinc, and a very good source of Dietary Fiber, Iron and Manganese (https://caloriebee.com/nutrition/The-Nutritional-And-Health-Benefits-Of-Cardamom).

Table 58. Effect of plant factor on growth and development of *C. sahyadriensis* on diets (Diet I_a - L_a)

Developmental Stages		Duration (days)			
		Diet I_a	**Diet J_a**	**Diet K_a**	**Diet L_a**
Egg		3.23 ± 0.09^{bc}	3.22 ± 0.09^{c}	3.25 ± 0.15^{b}	3.90 ± 0.10^{a}
Larval		17.30 ± 0.59^{c}	16.10 ± 0.25^{d}	17.90 ± 0.65^{b}	21.95 ± 0.35^{a}
Pre-pupa		2.49 ± 0.15^{bc}	2.40 ± 0.08^{b}	2.40 ± 0.20^{b}	3.30 ± 0.20^{a}
Pupa	Male	6.72 ± 0.17^{c}	6.65 ± 0.12^{d}	6.68 ± 0.50^{b}	8.40 ± 0.15^{a}
	Female	7.95 ± 0.29^{b}	7.80 ± 0.21^{c}	7.75 ± 0.26^{d}	9.25 ± 0.13^{a}
Adult longevity	Male	7.69 ± 0.20^{b}	7.25 ± 0.15^{d}	7.45 ± 0.18^{c}	8.10 ± 0.11^{a}
	Female	8.86 ± 0.24^{c}	8.50 ± 0.20^{d}	8.90 ± 0.10^{b}	9.20 ± 0.18^{a}
Total developmental period		38.66 ± 1.28^{c}	36.81 ± 0.77^{d}	38.94 ± 1.52^{b}	46.63 ± 0.94^{a}

Diets I_a-K_a contained varied quantities of plant powder (cardamom capsules); Diet L_a was without plant powder (Control); Means ± standard error (n=5) and means followed by different letters in the same columns are significantly different at p<0.05 (Analysis of Variance; Bonferroni test).

Table 59. Effect of adding plant powder on life cycle parameters of *C. sahyadriensis* on diets (Diet I_a - L_a)

Diets	Larval survival (%)	Pupation (%)	Pupal weight (mg)		Adult emergence (%)	Fecundity
			Male	Female		
Diet I_a	90.65 ± 1.15^{b}	91.25 ± 2.25^{b}	62.75 ± 0.85^{c}	83.30 ± 0.70^{b}	90.75 ± 1.35^{c}	25.75 ± 0.50^{b}
Diet J_a	91.66 ± 0.29^{a}	92.46 ± 1.22^{a}	63.81 ± 0.99^{a}	84.74 ± 0.88^{a}	95.80 ± 1.28^{a}	26.70 ± 0.66^{a}
Diet K_a	90.50 ± 1.10^{c}	90.25 ± 2.15^{c}	62.85 ± 0.70^{b}	82.50 ± 0.56^{c}	91.25 ± 1.50^{c}	24.95 ± 0.85^{c}
Diet L_a	79.75 ± 0.55^{d}	77.35 ± 1.85^{d}	56.75 ± 2.56^{d}	65.60 ± 1.75^{d}	74.40 ± 2.15^{d}	18.90 ± 0.45^{d}

Diets I_a-K_a contained varied quantities of plant powder (cardamom capsules); Diet L_a was without plant powder (Control); Means ± standard error (n=5) and means followed by different letters in the same columns are significantly different at p<0.05 (Analysis of Variance; Bonferroni test).

4.2b Effect of Casein on the growth and development of *C. punctiferalis* and *C. sahyadriensis* in artificial diets

The effect of incorporating casein for growth and development of *C. punctiferalis* on four diets is presented in Table 60. Among the four diets, Diet-F_b was the most preferred as it contained 35 g/ml of casein and recorded the highest percentage of larval survival (94.45 %), per cent pupation (92.50%), male and female pupal weight (56.80 and 63.15 mg, respectively), fecundity (28.50 eggs per female) and also found the shortest life cycle (39.95 days) compared to other diets. These results indicated that adding protein (Casein) at appropriate amounts favoured the growth and development of borer in normal meridic diet with appropriate plant fraction (Table 60).

The effect of incorporating casein for growth and development of *C. sahyadriensis* on four diets is presented in Table 61. Among the four diets, Diet-J_b was the most preferred as it contained 35 g/ml of casein and recorded the highest percentage of larval survival (92.26 %), per cent pupation (93.360%), fecundity (26.85 eggs per female) and found the shortest life cycle (37.81days) compared to other diets. These results indicated that adding protein (Casein) at appropriate amounts favoured the growth and development of borer, *C. sahyadriensis* in normal meridic diet with appropriate plant fraction (Table 61).

For insect optimal growth and development in artificial diets, amino acids are required in adequate proportions (Panizzi and Parra, 1991). Casein has been widely used in insect artificial diets because it contains all the essential amino acids generally obtained from bovine milk, soluble in water, and does not coagulate upon heating (Parra, 1979). Casein also contains traces of fatty acids, cholesterol, sugars, vitamins, and minerals (Vanderzant, 1966). Salvador *et al.* (2010) found high insect mortality with half concentration of casein in relation to the standard diet used for mass rearing *Anticarsia gemmatalis* Hübner, or without added casein. The diet based on casein, wheat germ and cellulose allowed the best development of *T. absoluta*, showing higher viability and no negative effects on larval instars and pupal weight (Bajonero and Parra, 2017).

Table 60. Effect of Casein on growth and development of *C. punctiferalis* on diets (Diet E_b – H_b)

Diets	Larval survival (%)	Pupation (%)	Pupal Weight (mg)		Adult emergence (%)	Fecundity	Total life cycle (days)
			Male	Female			
Diet E_b	89.50±0.95^c	86.36±2.65^c	51.65±2.10^c	59.85±1.50^c	85.50±1.40^c	22.25±0.50^c	41.00±1.56^c
Diet F_b	94.45±0.10^a	92.50±1.75^a	56.80±0.50^a	63.15±0.25^a	96.80±1.10^a	28.50±0.75^a	39.95±0.85^d
Diet G_b	91.10±0.75^b	88.25±2.80^b	53.55±1.45^b	60.25±1.45^b	90.60±2.15^b	24.28±0.29^b	42.90±0.35^b
Diet H_b	45.25±3.35^d	44.50±3.35^d	39.50±2.50^d	42.54±2.75^d	48.25±2.50^d	07.00±1.50^d	48.20±1.65^a

Diets E_b –G_b contained varied quantities of casein; Diet H_b was without casein (Control); Means± standard error (n=5) and means followed by different letters in the same columns are significantly different at p<0.05 (Analysis of Variance; Bonferroni test).

Table 61. Effect of Casein on growth and development of *C. sahyadriensis* on diets (Diet I_b-L_b)

Diets	Larval survival (%)	Pupation (%)	Pupal Weight (mg)		Adult emergence (%)	Fecundity	Total life cycle (days)
			Male	Female			
Diet I_b	86.10±0.25^c	84.15±1.95^c	59.65±0.65^b	70.00±1.06^c	88.95±1.40^c	21.60±0.45^c	41.85±1.80^b
Diet J_b	92.26±0.44^a	93.36±1.65^a	64.85±0.80^a	85.05±0.65^a	95.70±1.29^a	26.85±0.50^a	37.81±1.05^d
Diet K_b	88.50±1.05^b	89.75±1.95^b	57.65±2.45^c	76.35±1.45^b	90.50±1.80^b	25.75±0.60^b	40.65±1.55^c
Diet L_b	39.70±2.15^d	40.20±3.14^d	35.50±3.25^d	40.50±3.50^d	50.65±2.75^d	8.60±0.50^d	46.68±2.52^a

Diets I_b –K_b contained varied quantities of casein; Diet-L_b was without casein (Control); Means± standard error (n=5) and means followed by different letters in the same columns are significantly different at p<0.05 (Analysis of Variance; Bonferroni test).

4.2c Effect of Vit-E on fecundity of *C. punctiferalis* and *C. sahyadriensis* in artificial diets

In order to develop a refined artificial diet for *C. punctiferalis*, the effect of Vit-E tablets on growth and development of *C. punctiferalis* was studied. Vit-E is essential for producing viable eggs. Diet-F_c contained Vit-E capsule (1gm/ml) and recorded 95.20% larval survival, 92.50% pupation and 96.50% adult emergence (Table 62). The insects emerging as adults from Diet-F_c were qualitative compared to other diets. These data support the fact that Vit-E is also essential for growth and development of borer. This also holds good for other insects in general. Analysis of Variance and Bonferroni tests revealed significant differences in the growth and development parameters of *C. punctiferalis* on different diets (Table 62). Since Vit-E is implicated in the reproduction and production of fertile eggs, laboratory studies were conducted on the effect of Vit-E on borer fecundity (Table 63). The moths laid maximum number of viable eggs (29.28 eggs per female) on Diet-F_c compared to Diet-E_c and Diet-G_c. This trend was recorded in all the four successive generations (Table 63).

To develop a refined artificial diet for *C. sahyadriensis*, the effect of Vit-E tablets on growth and development of *C. sahyadriensis* was studied. Vit-E is essential for producing viable eggs. Diet-J_c contained Vit-E capsule (1gm/ml) and recorded 91.66% larval survival, 92.46% pupation and 95.80% adult emergence (Table 64). The insects emerging as adults from Diet-J_c were qualitative compared to other diets. These data support the fact that Vit-E is also essential for growth and development of borer, *C. sahyadriensis*. This holds good for other insects in general. Analysis of Variance and Bonferroni tests revealed significant differences ($p<0.05$) in the growth and development of *C. sahyadriensis* on different diets (Table 64). Since Vit-E is implicated in the reproduction and production of fertile eggs, laboratory studies were conducted on the effect of Vit-E on borer fecundity (Table 65). The moths laid maximum number of viable eggs (26.70 eggs per female) on Diet-J_c compared to Diet-I_c, Diet-K_c and Diet-L_c. This trend was recorded in all the four successive generations (Table 65).

Vitamin E although required in micro quantities, is essential for reproduction in insects, and enhances the fecundity (McFarlen, 1992). Vitamin E or α-tocopherol, as an important constituent of corn oil, soybean oil, wheat germ oil or wheat germ, has been in used in the artificial diets for rearing of insects (Vanderzant, 1956; Burton and Perkins, 1972; Senthilkumar, 1995). For example, vitamin E at 200 mg/ 400ml diet in the artificial diet resulted in higher larval and pupal survival and adult emergence. The fecundity of the *H. armigera* increased with an increase in Vitamin E in the artificial diet (Chitti Babu, 2012). Siddiqui and Sarup (1980) studied the impact of vitamin E 011 the fecundity of *C. partellus* and highlighted its impact on egg production. They reported that artificial diets deficient in vitamin E produced moths of *C. partellus* which laid less number of eggs. However, the optimal quantity of vitamin E required in diets was influenced by principal base-ingredients.

The composition of diet was water, rajmah grain powder, brewer's yeast, sorbic acid, vitamin E, methyl-para-hydroxybenzoate, ascorbic acid, sorghum leaf powder (Cultivar CSH-1), agar-agar, water and 40 per cent formaldehyde. They found that the total developmental period of *C. partellus* from larva to adult on this diet was 32 to 49 days. The mean recovery of moths was 59 per cent and the average number of eggs laid by an individual female was 495 eggs per female (Seshu Reddy and Davies, 1978).

House (1965) reported that Vitamins A and E accelerated the growth rate in *Agria affinis* (Fallén) and promoted development and the adult emergence increased. The development of males was especially improved, and the sex ratio no longer was abnormally imbalanced. The most noteworthy finding was that vitamin E was essential to the female to produce viable offspring. Thus, these fat-soluble vitamins can correct several long-standing defects in the larval nutrition of *A. affinis* that are reared axenically on chemically defined diets. Ahmad *et al.* (1998) reported that the modified diet with the addition of vitamin E which prevents a possible reduction in vigor and egg viability of insects. Charpentier (1979) showed the phago-stimulatory activity of Vit-E in *Scotia segetum*.

Table 62. Effect of Vitamin E on growth and development of *C. punctiferalis* on diets (Diet E_c – G_c)

Diets	Larval survival (%)	Pupation (%)	Pupal Weight (mg)		Adult emergence (%)	Total life cycle (days)
			Male	Female		
Diet E_c	89.20±0.15^c	90.05±2.10^b	56.95±0.25^b	60.95±1.05^b	95.50±2.20^b	42.50±0.25^b
Diet F_c	95.20±0.14^a	91.75±1.95^a	57.60±0.56^a	61.65±0.15^a	96.50±2.00^a	40.12±0.70^d
Diet G_c	92.65 ±0.25^b	88.35±0.85^c	52.65±2.30^c	59.35±2.25^c	80.50±1.25^c	41.90±0.35^c
Diet K_c	75.12±2.15^d	74.40±2.35^d	44.30±2.25^d	53.55±2.35^d	79.65±1.40^d	47.80±1.88^a

Diets E_c –G_c contained varied quantities of Vitamin E; Diet H_c was without Vitamin E (Control); Means± standard error (n=5) and means followed by different letters in the same columns are significantly different at p<0.05 (Analysis of Variance; Bonferroni test).

Table 63. Effect of Vitamin E on fecundity of *C. punctiferalis* on diets (Diet E_c-H_c)

Diets	Average number of eggs laid, *C. punctiferalis*			
	G_1	**G_2**	**G_3**	**G_4**
Diet E_c	26.10	25.20	11.40	2.60
Diet F_c	29.28	30.10	15.90	7.40
Diet G_c	27.10	26.40	10.10	2.40
Diet H_c	7.60	5.80	1.80	0.40

Diets E_c-G_c contained varied quantities of Vitamin E; Diet H_c was without Vitamin E(Control); n=5 pair of moths for each replicate; G_1-G_4 are successive generations

Table 64. Effect of Vitamin E on growth and development of *C. sahyadriensis* on diets (Diet I_c–L_c)

Diets	Larval survival (%)	Pupation (%)	Pupal Weight (mg)		Adult emergence (%)	Total life cycle (days)
			Male	Female		
Diet I_c	88.25±0.35^{c}	90.15±1.95^{b}	58.85±0.45^{c}	77.35±0.17^{c}	91.75±1.20^{b}	39.65±1.85^{c}
Diet J_c	91.66±0.24^{a}	92.46±1.82^{a}	63.85±0.95^{a}	84.95±0.68^{a}	95.80±1.28^{a}	37.81±0.75^{d}
Diet K_c	89.60±0.15^{b}	89.25±0.95^{c}	61.95±2.75^{b}	82.45 ±2.25^{b}	90.85±1.50^{c}	41.75±1.35^{b}
Diet L_c	74.00±1.25^{d}	73.60±2.54^{d}	45.35±3.15^{d}	53.15±3.35^{d}	75.10±2.15^{d}	45.63±2.44^{a}

Diets I_c –K_c contained varied quantities of Vitamin E; Diet-L_c was without Vitamin E (Control); Means± standard error (n=5) and means followed by different letters in the same columns are significantly different at p<0.05 (Analysis of Variance; Bonferroni test).

Table 65. Effect of Vitamin E on fecundity of *C. sahyadriensis* on diets (Diet I_c –L_c)

Diets	Average number of eggs laid, *C. sahyadriensis*			
	G_1	**G_2**	**G_3**	**G_4**
Diet I_c	24.90	25.80	14.90	6.30
Diet J_c	26.70	27.60	23.70	13.40
Diet K_c	21.60	23.10	18.10	7.70
Diet L_c	10.60	5.80	3.60	1.40

Diets I_c-K_c contained varied quantities of Vitamin E; Diet L_c was without Vitamin E (Control); n=5 pair of moths for each replicate; G_1-G_4 are successive generations; n=5 pair of moths for each replicate; G1-G4 are successive generations.

4.2d Effect of anti-microbial ingredients on growth and development of *C. punctiferalis* and *C. sahyadriensis* reared on artificial diets

One of the major hindrances in mass production of insects on artificial diets has been the microbial contamination. Therefore, the effect of antimicrobial ingredients on growth and development of *C. punctiferalis* on four diets was recorded. The diet without anti-microbial agents (Diet-H_d) recorded the least larval survival (11.75%), pupation (4.50%) and only about 6% adult emergence. When compared to the Diet-F_d which contained anti-microbial ingredients *viz*., sorbic acid (1g/ml), Methyl parahydroxy benzoate (2g/ml) and streptomycin sulphate (0.5g/ml) recorded the highest larval survival rate (95.50%), pupation (93.70%) and adult emergence (96.95%). The diet with appropriate quantity of anti-microbial ingredients showed higher percentage of fecundity (28.90 eggs per female) and survivability compared to other diets with no or negligible amounts of microbial ingredients (Table 66).

Microbial contamination is one of the major problems affecting the rearing of insects. Bacterial and fungal contaminants from insectary-reared insects were reviewed by Sikorowski and Lawrence (1994). Studies of Du *et al.* (2015) have indicated that diets having sorbic acid or formaldehyde as microbial inhibitors were unsuitable. Some workers like Du *et al.* (2015) derived the meridic diet for *C. punctiferalis* from close genera like the Oriental fruit moth, *Grapholitha molesta* (Busck) (Wang *et al.*, 2011).

One of the major hindrances in mass production of insects on artificial diets has been the microbial contamination. Therefore, the effect of antimicrobial ingredients on growth and development of *C. sahyadriensis* on four diets was recorded. The diet without anti-microbial agents (Diet-L_d) recorded the least larval survival (9.60%), pupation (3.50%) and only about 3.95% adult emergence. This when compared to the Diet-J_d which contained anti-microbial ingredients *viz*., sorbic acid (1g/ml), Methyl parahydroxy benzoate (2g/ml) and streptomycin sulphate (0.5g/ml) recorded the highest larval survival rate (93.20%), pupation (94.60%) and adult emergence (95.90%). The diet with appropriate quantity of anti-microbial ingredients showed higher percentage of fecundity (27.05 eggs

per female) and survivability compared to other diets which contain no or negligible amounts of microbial ingredients (Table 67).

Microbial contamination in insect artificial diet is often problematic with *Aspergillus niger*, *Aspergillus flavus*, *Cladosporium* spp., *Fusarium* spp., *Rhizopusnigricans*, *Penicillium* spp. and yeasts and bacteria (Zha and Cohen, 2014). Suppressing microbial growth in artificial diets is key to the success of mass rearing. Roeder *et al.* (2010) conducted studies on an antimicrobial agent, Diet Antimicrobial Agent (DAA) (Composed of five ingredients *viz*., propionic acid, phosphoric acid, sorbic acid, benzoic acid and chloramphenicol), and evaluated ability to suppress microbial growth against strains of *Heliothis virescens* Fabricus at Texas, USA. The results suggested that DAA is an effective suppressor of microbial growth on artificial diets.

The need to supplement the diets with anti-microbial substances *viz.*, formaldehyde, methyl-p-hydroxybenzoate, butyl-p-hydroxybenzoate, dichlorophene, pimaricin, chlorotetracycline, kanamiycin, di-hydrostreptomycin sulfate and sodium propionate is to inhibit the growth of fungi, yeast or bacteria (Singh and House, 1970; Krieg, 1971 and Singh 1977). Contaminations of stock cultures and artificial diet must be prevented for successful rearing of insects. Antimicrobial substances are often used in larval diets and eggs are treated with various antimicrobial washes. Before development of methods of egg surface sterilization (Paschke, 1964) and artificial diets containing microbial agents, high larval mortality resulting from nuclear polyhedrosis virus severely limited the rearing of insects on artificial diets.

In sum, the constituents of diet which supported *C. punctiferalis* growth and development will also have the impact on the insect in successive generations. This was tested in castor borer, *C. punctiferalis* (Table 68 and Fig. 18). Among the diets tested (Plate 17), diet-A proved the most suitable for growth and development of borer as the moths completed life cycle on an average in 40.12 days (n=20) (Plate 18). On diet-B, the insect could not complete the life cycle as it contained cardamom plant factor. On Diet-C, the insect required on an average 44.75 days to complete the life cycle (n=20). On Diet-D which was a natural host plant, the insect required on an average 45.13 days to complete

the life cycle (n=20). This trend was consistently noticed in all the four generations of the insect *i.e., C. punctiferalis* on four diets (Table 68).

There were statistically significant differences ($p<0.05$) between the mean total duration of moths reared on diet A and the natural host plant by Analysis of Variance and Bonferroni tests (Table 68). These observations suggest that artificial diet-A proved better for mass production of *C. punctiferalis* moths compared to the natural host plant. These results are in concurrence with the studies of Soniya and Kaur (2015), which suggested that overall performance of *Chilo auricilius* Dudgeon on artificial diet was found better than the natural diet.

The constituents of the diet supporting *C. sahyadriensis* growth and development will also have impact on the insect in successive generations. This was tested in cardamom borer, *C. sahyadriensis* (Table 69 and Fig. 19). Diet-B proved the most suitable for growth and development of borer as the moths completed the life cycle on an average in 38.65 days (n=20) (Plate 19). On diet-A, the insect could not complete the life cycle as it contained castor plant factor. On Diet-C, the insect required on an average 45.59 days to complete the life cycle (n=20). On Diet-D which was the natural host plant, the insect required 46.53 days to complete the life cycle (n=20). This trend was consistently noticed in all the four generations of the insect *i.e., C. sahyadriensis* on four diets (Table 69).

There were statistical significant differences ($p<0.05$) between the mean total duration of moths reared on diet B and the natural host plant by Analysis of Variance and Bonferroni tests (Table 69). These observations suggest that artificial diet-B proved better for mass production of *C. sahyadriensis* moths compared to the natural host plant. These results are in accordance with the studies of Han *et al.* (2012) that were conducted at the suburbs of Haidian District, Beijing, China who suggested that *C. suppressalis* reared on the artificial diet showed better performance with shorter developmental stage, similar larval survival rate and fecundity, and higher adult emergence compared to natural host plant. These results indicated that *C. suppressalis* adopted well to the artificial diet and successive rearing conditions. The diet could serve as a viable alternative to natural host plants for consecutive rearing of the insect.

Table 66. Effect of anti-microbial ingredients on growth and development of *C. punctiferalis* in diets (Diet E_d- H_d)

Diets	Larval survival (%)	Pupation (%)	Pupal Weight (mg)		Adult emergence (%)	Fecundity	Total life cycle (days)
			Male	Female			
Diet E_d	74.25±1.75^b	64.50±1.95^c	40.55±2.20^c	52.75±1.60^c	50.20±1.80^c	15.25±0.80^c	42.50±1.60^b
Diet F_d	95.50±0.40^a	93.70±1.25^a	57.50±0.70^a	64.25±0.15^a	96.95±1.15^a	28.90±0.25^a	39.75±0.65^d
Diet G_d	70.50±0.95^c	82.00±1.60^b	42.50±1.65^b	56.75±1.45^b	75.65±2.15^b	19.25±0.95^b	40.50±1.25^c
Diet H_d	11.75±3.75^d	4.50±3.25^d	32.70±3.50^d	38.50±2.70^d	5.75±3.50^d	03.50±2.40^d	49.80±3.85^a

Diets E_d –G_d contained varied quantities of anti-microbial ingredients; Diet H_d was without anti-microbial ingredients (Control); Means± standard error (n=5) and means followed by different letters in the same columns are significantly different at p<0.05 (Analysis of Variance; Bonferroni test).

Table 67. Effect of anti-microbial ingredients on growth and development of *C. sahyadriensis* on diets (Diet I_d –L_d)

Diets	Larval survival (%)	Pupation (%)	Pupal weight (mg)		Adult emergence (%)	Fecundity	Total life cycle (days)
			Male	Female			
Diet I_d	58.50±1.25^c	61.25±1.85^c	48.65±0.50^c	54.20±1.60^c	59.85±1.50^c	16.70±0.50^c	42.85±1.90^b
Diet J_d	93.20±0.50^a	94.60±0.95^a	64.95±0.95^a	86.15±0.75^a	95.90±1.25^a	27.05±0.70^a	36.95±1.15^d
Diet K_d	71.50±1.50^b	70.85±2.05^b	49.75±2.55^b	58.45±1.35^b	62.60±1.95^b	18.75±0.40^b	41.25±1.65^c
Diet L_d	9.60±2.56^d	03.50±3.60^d	29.80±3.85^d	33.25±3.75^d	3.95±3.95^d	2.90±0.50^d	49.80±2.75^a

Diets I_d –K_d contained varied quantities of anti-microbial ingredients; Diet-L_d was without anti-microbial ingredients (Control); Means± standard error (n=5) and means followed by different letters in the same columns are significantly different at p<0.05 (Analysis of Variance; Bonferroni test).

Table 68. A Comparison of life stages of *C. punctiferalis* reared on artificial diets and natural host plant for four generations

Fitness parameters	Generations	Diets			
		Diet-A	Diet-B	Diet-C	Diet-D
Egg (d)	G1	3.20 ±0.17^{c}	4.20 ±0.17^{a}	4.10 ±0.06^{b}	4.20 ±0.17^{a}
	G2	2.92 ±0.15^{c}	4.52 ±0.09^{a}	3.52 ±0.18^{b}	3.20 ±0.17^{bc}
	G3	3.25 ±0.15^{b}	4.25 ±0.11^{a}	3.25 ±0.08^{b}	3.25 ±0.08^{b}
	G4	3.10 ±0.12^{c}	4.10 ±0.06^{a}	4.10 ±0.06^{a}	3.38 ±0.08^{b}
	Mean	3.12 ±0.07^{c}	4.27 ±0.09^{a}	3.74 ±0.21^{b}	3.61 ±0.24^{bc}
Larva (d)	G1	16.95 ±0.08^{b}	4.22 ±0.16^{c}	18.85 ±0.29^{a}	18.85 ±0.29^{a}
	G2	17.50 ±0.25^{b}	4.25 ±0.14^{c}	19.10 ±0.27^{a}	19..15 ±0.29^{a}
	G3	15.95 ±0.28^{b}	4.10 ±0.12^{c}	19.15 ±0.29^{a}	19.25 ±0.29^{a}
	G4	17.40 ±0.30^{b}	4.50 ±0.15^{c}	19.50 ±0.22^{a}	19.75 ±0.11^{a}
	Mean	16.95 ±0.35^{c}	4.27 ±0.08^{b}	19.15 ±0.13^{a}	19.25 ±0.19^{a}
Pre-pupa (d)	G1	2.13 ±0.10^{b}	-	2.50 ±0.05^{a}	2.50 ±0.05^{a}
	G2	2.25 ±0.11^{a}	-	2.12 ±0.06^{b}	2.15 ±0.10^{b}
	G3	1.95 ±0.05^{b}	-	2.25 ±0.08^{a}	2.25 ±0.08^{a}
	G4	2.25 ±0.07^{b}	-	2.70 ±0.06^{a}	2.75 ±0.08^{a}
	Mean	2.15 ±0.07^{b}	-	2.39 ±0.13^{a}	2.41 ±0.13^{a}
Pupa (d)	G1	8.95 ±0.13^{b}	-	10.00 ±0.33^{a}	10.10 ±0.28^{a}
	G2	8.25 ±0.08^{b}	-	9.50 ±0.12^{a}	9.25 ±0.08^{a}
	G3	9.15 ±0.06^{b}	-	9.90 ±0.04^{a}	9.9 ±0.04a
	G4	8.85 ±0.15^{b}	-	10.20 ±0.24^{a}	10.20 ±0.24^{a}
	Mean	8.80 ±0.19^{b}	-	9.90 ±0.15^{a}	9.86 ±0.21^{a}
Adult longevity (d)	G1	9.20 ±0.19^{b}	-	9.09 ±0.06^{c}	10.50 ±0.12^{a}
	G2	8.95 ±0.05^{b}	-	9.50 ±0.12^{c}	9.75 ±0.18^{a}
	G3	8.75 ±0.21^{b}	-	9.70 ±0.09^{c}	9.95 ±0.02^{a}
	G4	9.50 ±0.14^{b}	-	9.95 ±0.02^{a}	9.95 ±0.02^{a}
	Mean	9.10 ±0.16^{c}	-	9.56 ±0.18^{b}	10.04 ±0.16^{a}
Total developmental period (d)	G1	40.13 ±0.14^{c}	8.65 ±0.20^{d}	44.25 ±0.14^{b}	45.50 ±0.18^{a}
	G2	39.95 ±0.17^{b}	8.95 ±0.20^{c}	43.75 ±0.21^{a}	43.80 ±0.25^{a}
	G3	39.90 ±0.20^{b}	8.90 ±0.23^{c}	45.20 ±0.24^{a}	45.25 ±0.19^{a}
	G4	40.50 ±0.11^{b}	8.95 ±0.20^{c}	45.80 ±0.18^{a}	45.95 ±0.20^{a}
	Mean	40.12 ±0.14^{b}	8.86 ±0.07^{c}	44.75 ±0.46^{a}	45.13 ±0.46^{a}

Diet A-C are meridic diets and Diet-D, natural food (Control); G_1 to G_4 are successive generations established from wild caught larvae; Means± standard error (n=20) and means followed by different lowercase letters in the same row are not significantly different at p>0.05 (Analysis of Variance; Bonferroni test).

Table 69. A Comparison of life stages of *C. sahyadriensis* reared on artificial diets and natural host plant for four generations

Fitness parameters	Generations	Diets			
		Diet-A	Diet-B	Diet-C	Diet-D
Egg (d)	G1	5.10 ±0.17^{a}	3.50 ±0.14^{c}	4.20 ±0.17^{b}	4.25 ±0.18^{b}
	G2	4.90 ±0.13^{a}	3.00 ±0.01^{b}	3.25 ±0.15^{b}	3.25 ±0.15^{b}
	G3	4.25 ±0.08^{a}	2.95±0.03^{c}	3.50 ±0.12^{b}	3.75 ±0.16^{b}
	G4	5.35 ±0.10^{a}	3.50 ±0.14^{c}	4.50 ±0.12^{b}	4.50 ±0.12^{b}
	Mean	4.90 ±0.24^{a}	3.24 ±0.15^{b}	3.86 ±0.29^{b}	3.94 ±0.28^{b}
Larva (d)	G1	4.95 ±0.09^{d}	17.25 ±0.16^{c}	21.95 ±0.29^{b}	22.85 ±0.31^{a}
	G2	3.50 ±0.32^{c}	16.85 ±0.20^{b}	19.50 ±0.08^{a}	19..25 ±0.08^{a}
	G3	4.95 ±0.09^{c}	17.60 ±0.12^{b}	20.25 ±0.22^{a}	20.50 ±0.22^{a}
	G4	4.75 ±0.21^{c}	17.50 ±0.16^{b}	22.75 ±0.45^{a}	21.95 ±0.29^{a}
	Mean	4.54 ±0.35^{c}	17.30 ±0.17^{b}	21.11 ±0.75^{a}	21.14 ±0.79^{a}
Pre-pupa (d)	G1	-	3.10 ±0.22^{b}	3.10 ±0.22^{b}	3.85 ±0.10^{a}
	G2	-	2.10 ±0.12^{c}	2.90 ±0.17^{a}	2.50 ±0.08^{b}
	G3	-	2.30±0.20^{b}	3.00 ±0.07^{b}	3.25 ±0.19^{a}
	G4	-	2.50 ±0.08^{c}	3.50 ±0.15^{b}	3.80 ±0.09^{a}
	Mean	-	2.50 ±0.22^{b}	3.13 ±0.13^{b}	3.35 ±0.31^{a}
Pupa (d)	G1	-	7.50 ±0.19^{c}	8.85 ±0.22^{b}	9.25 ±0.08^{a}
	G2	-	7.00 ±0.21^{c}	8.25 ±0.08^{a}	8.30 ±0.05^{a}
	G3	-	7.25 ±0.19^{c}	8.50 ±0.14^{b}	8.70 ±0.14^{a}
	G4	-	7.50 ±0.02^{c}	8.95 ±0.17^{b}	9.25 ±0.26^{a}
	Mean	-	7.31 ±0.12^{c}	8.64 ±0.16^{b}	8.86 ±0.22^{a}
Adult longevity (d)	G1	-	8.60 ±0.17^{b}	9.20 ±0.12^{a}	9.25 ±0.11^{a}
	G2	-	7.65 ±0.47^{b}	8.50 ±0.19^{b}	8.75 ±0.28^{a}
	G3	-	7.95 ±0.30^{b}	8.70 ±0.18^{ab}	9.15 ±0.13^{a}
	G4	-	8.95 ±0.15^{b}	8.95 ±0.15^{b}	9.75 ±0.16^{c}
	Mean	-	8.29 ±0.30^{b}	8.84 ±0.15^{ab}	9.23 ±0.21^{a}
Total developmental period (d)	G1	9.65 ±0.26^{d}	38.75 ±0.18^{c}	45.80 ±0.21^{b}	46.95 ±0.18^{a}
	G2	9.20 ±0.19^{c}	37.95 ±0.41^{b}	44.75 ±0.30^{a}	45.50 ±0.34^{a}
	G3	9.25 ±0.19^{c}	38.95 ±0.24^{b}	45.85 ±0.28^{a}	45.90 ±0.26^{a}
	G4	9.75 ±0.17^{d}	38.95 ±0.18^{c}	45.95 ±0.38^{b}	47.75 ±0.42^{a}
	Mean	9.46 ±0.14^{c}	38.65 ±0.24^{b}	45.59 ±0.28^{a}	46.53 ±0.51^{a}

Diets A-C are meridic diet and Diet D, natural food (Control); G_1 to G_4 are successive generations established from wild caught larvae; Means± standard error (n=20) and means followed by different lowercase letters in the same row are not significantly different at p>0.05 (Analysis of Variance; Bonferroni test).

Diet-A proved superior in adult size, fecundity and hatchability of *C. punctiferalis* eggs (Tables 70 and 71). But diet-A was costlier than another diet and natural host plant. In diet-A length of adult wings was longer by about 0.5 mm to 0.80 mm and breadth of wings greater by 0.85 mm (Table 70). Number of eggs were higher by 4 to 6 eggs per female on diet-A. The per cent hatchability of eggs increased by about 12% compared to the natural host plant (Table 71).

Diet-B proved superior in adult size, fecundity and hatchability of *C. sahyadriensis* eggs (Tables 70 and 72). Diet-B was costlier than another diet and natural host plant. Length of adult wings in male was lengthier in diet-B by about 0.7mm, breadth by about 0.5mm. In female, corresponding figures are about 0.50 mm and 0.65 mm, respectively (Table 70). Fecundity of female moths was higher by about 5 eggs per female on diet-B compared to natural host and egg hatchability by about 10% in adults reared on diet-B compared to those reared on natural host (Table 72). The sex ratio of male to female remained almost 1:1.20 in the two diets tested and on the host plant. This was with respect to the *C. punctiferalis* and *C. sahyadriensis* on castor and cardamom, respectively (Tables 71 and 72). The results were consistent with respect to the parameters *viz.,* adult size, fecundity of gravid females and the hatchability of eggs in successive generations of the two species of crambid moths. This was in respect to both the species of *Conogethes* investigated. The cost of mass rearing *C. punctiferalis* and *C. sahyadriensis* on artificial diets worked out to be Rs. 62/- only for one kg diet (Table 73). When the insects are reared on large scale it is likely that the costs will further reduce, and it is concluded that mass rearing of *Conogethes* spp can be rendered economically feasible under South Indian conditions.

Results of the current study corroborate with the results of Soniya and Kaur (2015) who reported that number of female moths was higher than male number when the sugarcane stalk borer, *Chilo auricillus* Dudgeon was reared on artificial diets compared to the natural host-plant. The number of eggs laid per *C. suppressalis* female ranged from 88.6 to 124.3 during fourth to 15^{th} generations with no significant differences between generations. But a positive relationship between the number of eggs laid and generation numbers was observed over 15 successive generations of rearing on the artificial diet (Han *et al.,* 2012).

Table 70. Effect of diets on *C. punctiferalis* and *C. sahyadriensis* adult size

Mean adult body size* (mm)		*C. punctiferalis*			*C. sahyadriensis*		
		Diet-A	**Diet- C**	**Diet-D**	**Diet-B**	**Diet-C**	**Deit-D**
Male	**Length**	12.14 ±0.25^{a}	10.78 ±0.29^{b}	11.65 ±0.38^{a}	12.85 ±0.05^{a}	11.25 ±0.12^{c}	12.16 ±0.42^{b}
	Breadth	23.95 ±0.14^{a}	21.75 ±0.30^{b}	23.10 ±0.28^{b}	25.85 ±0.13^{a}	24.30 ±0.23^{c}	25.28 ±0.20^{b}
Female	**Length**	13.25 ±0.07^{a}	11.90 ±0.23^{b}	12.85 ±0.20^{a}	14.95 ±0.03^{a}	13.90 ±0.32^{b}	14.50 ±0.17^{a}
	Breadth	25.35 ±0.39^{a}	23.80 ±0.09^{c}	24.50 ±0.21^{b}	27.90 ±0.50^{a}	26.80 ±0.30^{b}	27.25 ±0.37^{ab}
Mean size**	**Male**	290.75 ±0.04	234.47 ±0.09	269.12 ±0.11	332.17 ±0.01	273.38 ±0.02	307.40 ±0.08
	Female	335.89 ±0.03	283.22 ±0.02	314.83 ±0.04	417.11 ±0.02	372.52 ±0.10	395.13 ±0.06

*Diets A and C are meridic diets and Diet-D, natural food (Control); Means± standard error (n=10), and means followed by different letters in the same row are not significantly different at p>0.05 (Analysis of Variance; Bonferroni test); * represents the breadth of wing expansion; ** represents mean of length x breadth (Length- head to abdomen tip and Breadth- From one tip of wing of one side to the tip of wing of the other side).*

Table 71. Effect of diets on *C. punctiferalis* fecundity and egg viability

Fitness parameters	Generations	Diets		
		Diet-B	Diet-C	Diet-D
Adult emergence (%)	G1	96.50 ±0.26[a]	79.50 ±0.19 [c]	80.50 ±0.13[b]
	G2	96.75 ±0.08[a]	78.50 ±0.26 [c]	80.25 ±0.08 [b]
	G3	97.50 ±0.214[a]	78.75 ±0.11[c]	81.00 ±0.31 [b]
	G4	95.25 ±0.35[a]	77.65 ±0.82[c]	80.25 ±0.08 [b]
	Mean	96.50 ±0.42[a]	78.60 ±0.33[c]	80.50 ±0.23 [b]
Sex ratio (M:F ratio) *	G1	1:1.18	1:1.15	1:1.09
	G2	1:1.30	1: 0.85	1:1.20
	G3	1:1.40	1: 0.78	1:1.25
	G4	1: 1.45	1:1.80	1:1.25
	Mean	1:1.32	1: 0.90	1:1.15
Fecundity (Average no. of eggs laid/female)	G1	27.95 ±0.47[a]	23.45 ±0.33[c]	26.70 ±0.22[b]
	G2	31.25 ±0.51[a]	23.25 ±0.27[c]	27.10 ±0.47[b]
	G3	30.50 ±0.31[a]	22.15 ±0.17[c]	26.50 ±0.16 [b]
	G4	29.15 ±0.19[a]	21.75 ±0.34[c]	25.55 ±0.25[b]
	Mean	29.71 ±0.73[a]	22.65 ±0.41[c]	26.46 ±0.33[b]
Egg hatchability (%)	G1	90.95 ±0.18[a]	71.25 ±0.38[c]	80.25 ±0.21[b]
	G2	92.95 ±0.28[a]	74.5 ±0.32[c]	79.50 ±0.21[b]
	G3	91.50 ±0.15[a]	73.20 ±0.18[c]	79.00 ±0.06 [b]
	G4	91.25 ±0.12[a]	70.95 ±0.28[c]	78.50 ±0.18 [b]
	Mean	91.66 ±0.44[a]	72.35 ±0.29[c]	79.26 ±0.31[b]
Cost of diet (1000 ml) (Rs.)	-	80.45	50.95	46.50

*Diets A and C are meridic diets and Diet-D, natural food (Control); G_1 to G_4 are successive generations established from wild caught larvae; Means± standard error (n=10) and means followed by different letters in the same row are not significantly different at p>0.05 (Analysis of Variance; Bonferroni test); * represents the sample size of each mean (n=15).*

Table 72. Effect of diets on *C. sahyadriensis* fecundity and egg viability

Fitness parameters	Generations	Diets		
		Diet-B	**Diet-C**	**Diet-D**
Adult emergence (%)	G1	95.50 ±0.34[a]	74.50 ±0.19[b]	83.50 ±0.22[c]
	G2	96.75 ±0.08[a]	78.50 ±0.89[b]	84.25 ±0.29[c]
	G3	95.50 ±0.27[a]	75.70 ±0.05[b]	83.00 ±0.02[c]
	G4	95.25 ±0.35[a]	77.50 ±0.85[b]	84.25 ±0.29[c]
	Mean	95.80 ±0.18[a]	75.30 ±0.12[b]	83.75 ±0.14[c]
Sex ratio (M:F ratio) *	G1	1: 1.25	1: 1.10	1: 1.15
	G2	1: 1.30	1: 0.80	1: 1.20
	G3	1: 1.20	1: 0.75	1: 1.15
	G4	1: 1.25	1: 1.90	1: 1.20
	Mean	1: 1.25	1: 0.89	1: 1.18
Fecundity (Average no. of eggs laid/female)	G1	26.50 ±0.00[a]	19.45 ±0.37[b]	22.70 ±0.07[c]
	G2	26.85 ±0.09[a]	22.25 ±0.18[b]	22.10 ±0.13[c]
	G3	27.85 ±0.50[a]	18.50 ±0.31[b]	21.50 ±0.16[c]
	G4	25.75 ±0.11[a]	18.25 ±0.29[b]	20.55 ±0.12[c]
	Mean	26.74 ±0.28[a]	19.61 ±0.77[b]	21.71 ±0.10[c]
Egg hatchability (%)	G1	90.50 ±0.27[a]	71.25 ±0.38[b]	80.50 ±0.22[c]
	G2	91.75 ±0.40[a]	72.50 ±0.55[b]	81.50 ±0.25[c]
	G3	91.15 ±0.24[a]	72.20 ±0.29[b]	80.35 ±0.55[c]
	G4	90.91 ±0.11[a]	71.58 ±0.10[b]	78.50 ±0.18[c]
	Mean	90.25 ±0.13	70.35 ±0.36	78.50 ±0.34
Cost of diet (1000 ml) (Rs.)	-	82.50	50.95	48.50

*Diets B and C are meridic diets and Diet-D, natural food (Control); G_1 to G_4 are successive generations established from wild caught larvae; Means± standard error (n=10) and means followed by different letters in the same row are not significantly different at p>0.05 (Analysis of Variance; Bonferroni test); * represents the sample size of each mean (n=15).*

Table 73. Economics of standard diets used for mass rearing shoot and capsule borer, *C. punctiferalis* and *C. sahyadriensis*

Ingredients	Quantity (gm/ml)	Cost (Rs.)
Bengal gram powder	115	2.35
Cardamom/Castor leaf powder	85	4.5
Yeast powder	25	4
Casein	35	17.5
Sucrose	15	1.5
Distilled water	325	0.65
Agar-agar	15	13.5
Distilled water	300	0.6
Ascorbic acid	3	3.5
Wesson's salt mixture	1.5	2.5
Sorbic acid	1	0.5
Multivitamin, multimineral capsules	2 no's	1.2
Methyl parahydroxy benzoate	2	0.75
Strepomycin sulphate	0.5	1.25
Vit. E capsule USP 400mg	4 no's	2.5
Distilled water	75	0.15
Labour charge	0	2
Electricity charge	0	2.5
Total	**1kg**	**61.45**

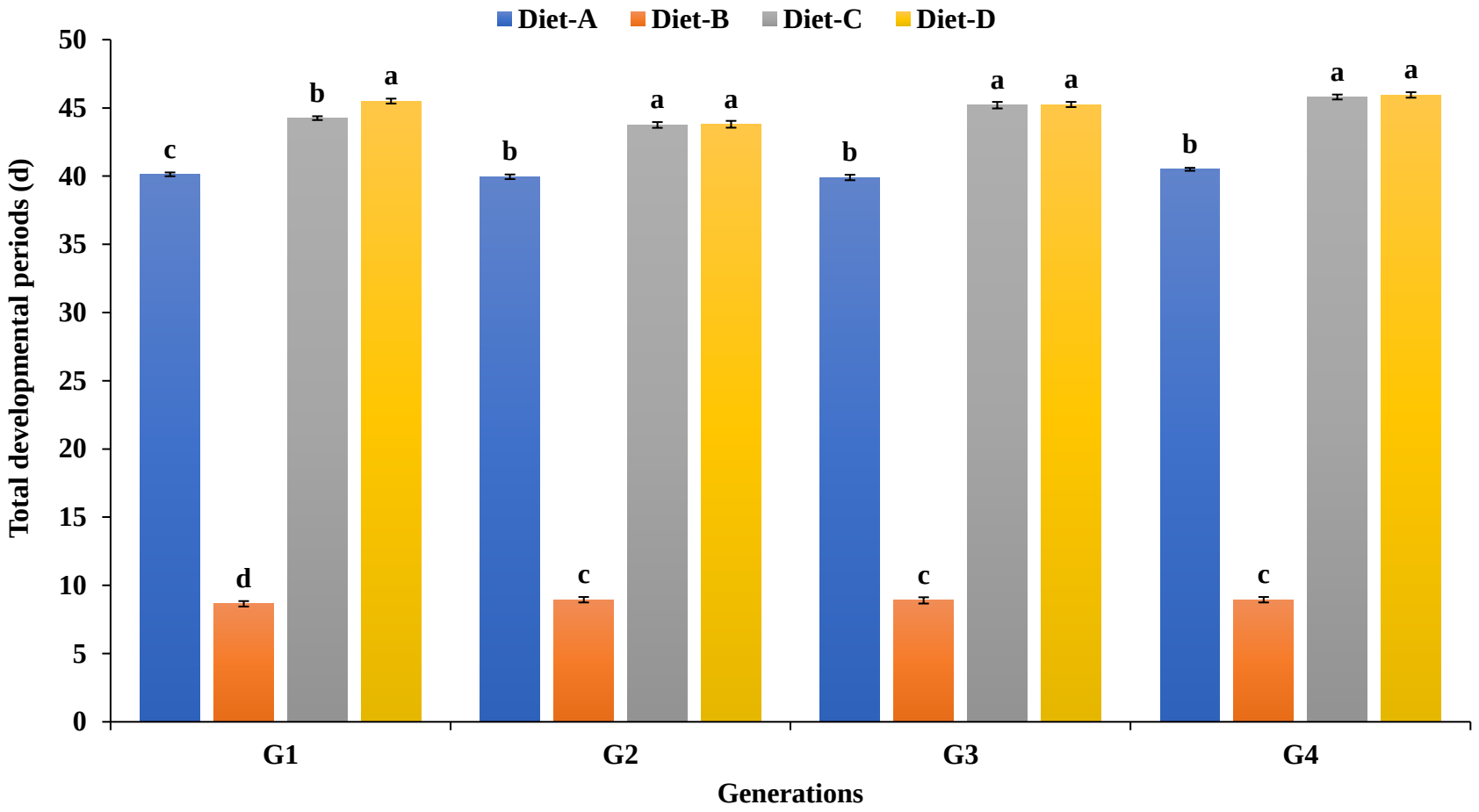

Fig. 18. Duration of four generations of *C. punctiferalis* on diets.

G_1 to G_4 are successive generations established from wild caught larvae; Bars present means ± standard error (n=20); significant differences among four diets are indicated by different lowercase letters on each bar (Bonferroni test, P<0.05).

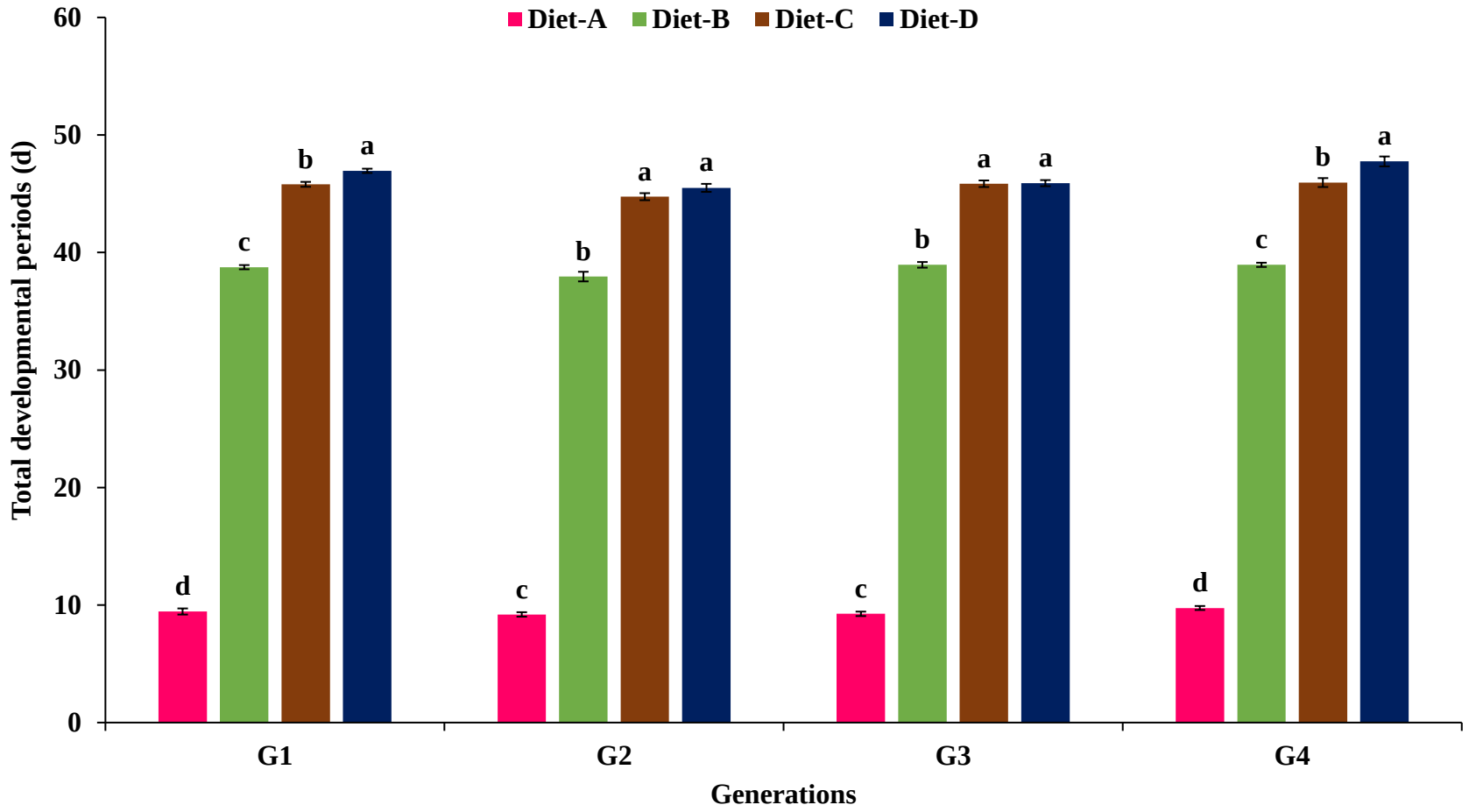

Fig. 19. Duration of four generations of *C. sahyadriensis* on diets.

G_1 to G_4 are successive generations established from wild caught larvae; Bars present means ± standard error (n=20); significant differences among four diets are indicated by different lowercase letters on each bar (Bonferroni test, P<0.05.

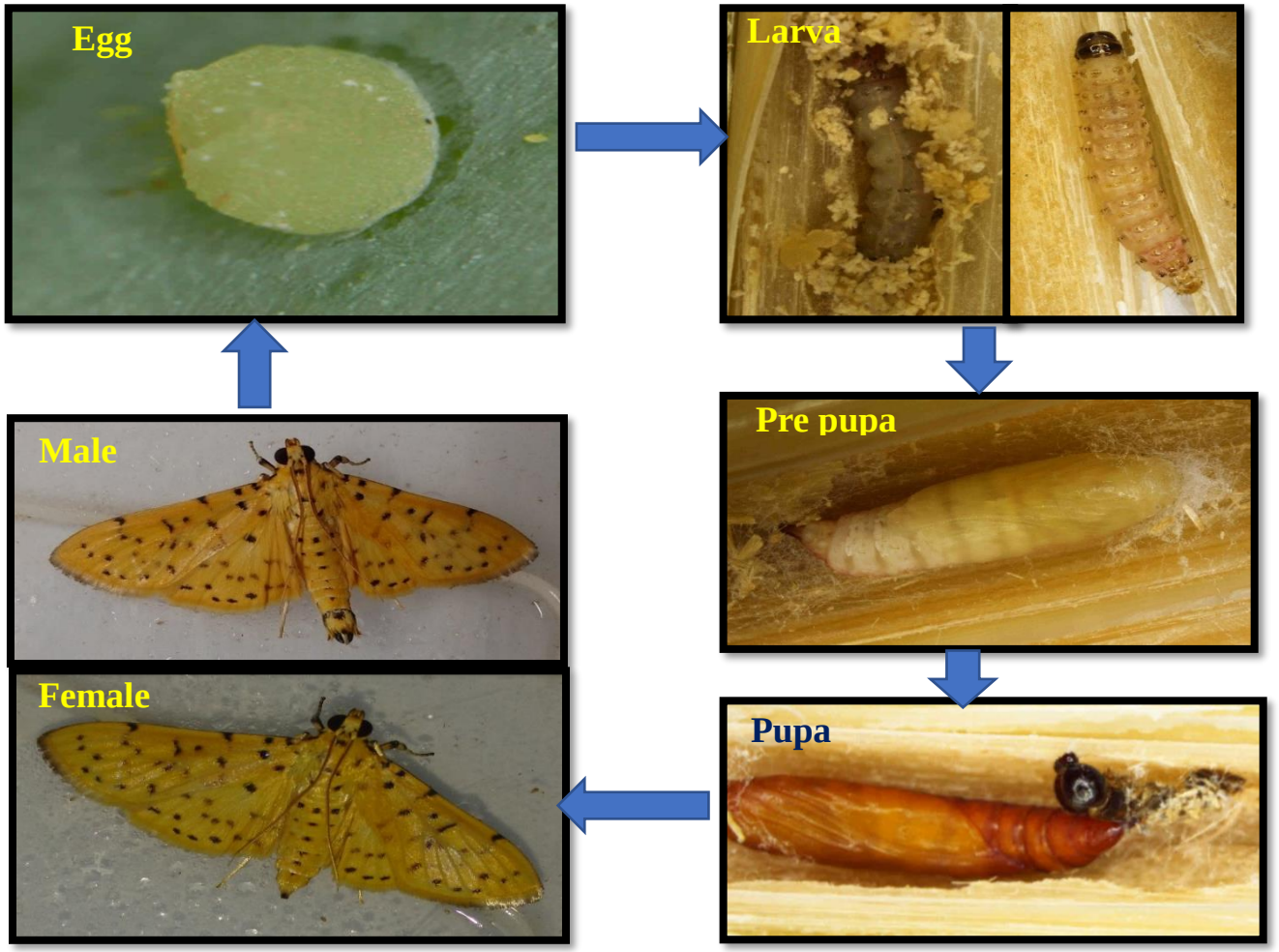

Plate 19. Life stages of Cardamom Borer, *C. sahyadriensis*

4.3 Field evaluation of identified pheromone components of *C. punctiferalis*

4.3.1 *C. punctiferalis* moths trapped in different traps at Tumkur and GKVK, Bengaluru

Four types of traps were evaluated for trapping male *C. punctiferalis* moths in castor field at two locations *viz*., Gangasagar, Pavgada, Tumkur (Dist.) and Dryland Agricultural Research Station, GKVK, Bengaluru (Table 74 and Fig. 20). For each type, a controlled trap was run without lure. The difference in number of moths trapped in different types was significant. Delta trap with lure attracted and trapped maximum number of moths at Gangasagar (58 moths/4 traps, average =14.50 moths /trap) (Plate 20) and GKVK, Bengaluru (54 moths/4 traps) in 104 days when the castor crop was at reproductive stage (65 days after sown). The water trap with lure attracted and trapped (34 moths / 4 traps, average=8.50 moths/trap) and it was most effective trap next to Delta trap. Consistent results to this efficacy were obtained at both the locations. The Delta trap with lure proved most effective for trapping male *C. punctiferalis* moths and it was statistically significant in trapping moths compared to other traps (at Gangasagar, SEm= 0.80, CD ($p \leq 0.05$) =2.34 and at GKVK, SEm= 1.11, CD ($p \leq 0.05$) =3.27). The Cross-vane trap and funnel traps were not effective either for monitoring or trapping *C. punctiferalis* moths. The lure attracted moths for 60 days, so there is a need to change lure once in 60 days. Similar experiment conducted in cardamom plantation at ZAHRS, Mudigere and found that there is no attraction and trapping of moths. These results confirmed that pheromone components are species specific, this was proved that trap with lure of *C. punctiferalis* in cardamom plantations had no catches as it infested by *C. sahyadriensis*.

Pheromone-baited traps provide a highly sensitive means of detecting and specifically monitoring adult moth population even at low densities (Srivastava and Srivastava, 1989). Most of the workers (Liu *et al*., 1994; Kimura and Honda, 1999; Jung *et al.,* 2000 and Shashank, 2012) on *C. punctiferalis* have identified three components *viz*., (*E*)-10-hexadecenal (E10-16:Ald), (*Z*)-10-hexadecenal (Z10-16:Ald) and hexadecenal (16:Ald) which are effective in attracting *C. punctiferalis* moths. The sex pheromone of *C. punctiferalis* calling females as a blend of (*E*)-10-hexadecenal (E10-16:Ald), (*Z*)-10-hexadecenal (Z10-16:Ald) and hexadecenal (16:Ald) was identified and detected with the

Electroantennography (EAG) and gas chromatogram–electroantennogram (GC-EAD) by Shashank (2012). This synthetic sex pheromone blend was used for standardization of trapping technology in castor field against castor shoot and capsule borer. Field tests indicated that E10-16:Ald, Z10-16:Ald and 16:Ald could effectively attract more male moths in 100:8:16. However, a small number of male moths was caught in the experiment. This might be due to the small number of *C. punctiferalis* adult emergence at that time or because of other weather conditions (temperature, humidity, rainfall, *etc.*,). Mass trapping is expected to reduce the populations by trapping the males so that next generations will be controlled. So small number of moth catches are expected with timely deployment of mass trapping technology.

Liu *et al.* (1994) identified (Z)-10-hexadecenal (Z10-16: Ald) and hexadecenal (16: Ald) are two minor components along with the major component, (E)-10-hexadecenal (E10-16: Ald), of the sex pheromone of the pyralid *C. punctiferalis*. Analysis of single sex pheromone gland extracts by capillary gas chromatography indicated that the relative ratio of 16: Ald, E10-16: Ald and Z10-16: Ald was 13.0: 80.4: 6.6. Field trials in Shandong, China, in 1987 indicated that Z10-16: Ald and 16: Ald alone caught no males. The most attractive was a blend containing 16: Ald, E10-16: Ald, and Z10-16: Ald at 16: 100: 8, and a two-compound blend of E10-16: Ald and Z10-16: Ald at 100: 8.

Chakravarthy and Thyagaraj (1998) trapped this species using 9:1 for (E)-10-hexadecenal and (Z)-10- hexadecenal in the field trials in Karnataka, India. This blend has been used for mass-trapping, monitoring, and mating disruption in Japan, Korea, and China (Kimura and Honda, 1999). In Korea, an 80:20 ratio of (E)-10-hexadecenal and (Z)-10-hexadecenal had the highest attractiveness in orchards (Jung *et al.*, 2000). Further work by Xiao et al. (2012) found that certain hydrocarbons had a synergistic effect on responses to pheromones. (E)- and (Z)-8-tetradecenyl formate have been synthesized and tested for effectiveness in trapping *C. punctiferalis*.

Four types of traps were evaluated for trapping male *C. punctiferalis* moths in castor field at two locations *viz*., Gangasagar, Pavgada, Tumkur (Dist.) and Dryland Agricultural Research Station, GKVK, Bengaluru. The Delta trap with lure proved most

effective for trapping male *C. punctiferalis* moths and it was statistically significant in trapping moths compared to other traps. The lure inside the delta traps attracts the moths near to the traps and further the moths oriented inside the trap whose inner surface lased with glue, the parts of the body coming contact with glue and moths get stuck. The chance for escape is almost nil. Similar line of work has been done by Youmi and Beevor (1995) who conducted experiment in Niger to compare pheromone-baited trapping system for monitoring male moths of the millet stem borer, *Coniesta ignefusalis* (Hampson). pheromone baited (blend of (Z)-7-do-decen-1-ol(Z7-12:OH) (500µg) + (Z)-5-decen-1-ol-(Z5-10:OH) (25 µg) + (Z)-7-dodecenal (Z7-12:CHO) (16.67µg) and an equal amount of BHT antioxidant) five traps *viz*., water oil trap, sticky bpard trap, plastic funnel trap, delta trap and sticky wing trap were tested and found that the water oil trap was more effective than other traps.

A blend of E-10-hexadecenal and Z-10-hexadecenal at 90:10 ratio was the most attractive *Conogethes* species in the field (Rajabaskar and Regupathy 2012). Recently, 16 formulations of sex pheromones and corresponding lures were developed with different compositions, ratios and dosages of (E)-10-hexadecenal (E-16:Ald), (Z)-10-hexadecenal (Z-16:Ald), and hexadecanal (16:Ald), and the field trapping tests were conducted to investigate their efficiencies. The results showed that the number of moths trapped by formulation D400-1:4 ((Z-16:Ald): (E-16:Ald)=1:4 and the dose used was 400.0 µg) was the highest among the 16 tested formulations (Du *et al.*, 2014b).

Studies on a comparison of attractiveness of the optimum synthetic pheromone blend and virgin female *C. ignefusalis* moths, water traps baited with the synthetic blend dispensed from a polyethylene vial at a loading of 1 mg Z7-12: OH, caught more than twice as many male *C. ignefusalis* moths as traps baited with a single virgin female moth (Beevor *et al.,* 1999). Field trapping studies were conducted in Conghua, Guangzhou, China using sex pheromone of *Diaphania angustalis.* More male moths were captured by traps baited with the mixture of E10E2-16:Ald and E10E2-16:OH in a ratio of 9:1, whereas a mixture of 8:1 and 10:1 also caught males (Ma *et al.*, 2017).

Table 74. Catches of male *C. punctiferalis* moths in different traps in castor field

Trap type	Gangasagar, Pavagada, Tumkur		GKVK, Bengaluru	
	Total number of moths trapped/4 traps	Mean ± SD	Total number of moths trapped/4 traps	Mean ± SD
Delta trap with lure	58.00	14.50 ±1.91 (3.87) [a]	54.00	13.50 ±4.12 (3.74) [a]
Delta trap without lure	8.00	2.00 ±1.41 (1.58) [cd]	7.00	1.75 ±0.50 (1.50) [c]
Cross vane trap with lure	13.00	3.25 ±2.22 (1.94) [c]	14.00	3.50 ±1.91 (2.00) [c]
Cross vane trap without lure	3.00	0.75 ±0.96 (1.12) [d]	6.00	1.50 ±1.29 (1.41) [c]
Funnel trap with lure	6.00	1.50 ±0.58 (1.41) [cd]	10.00	2.50 ±0.58 (1.73) [c]
Funnel trap without lure	4.00	1.00 ±0.82 (1.22) [cd]	5.00	1.25 ±0.50 (1.32) [c]
Water trap with lure	34.00	8.50 ±3.42 (3.00) [b]	38.00	9.50 ±3.11 (3.16) [b]
Water trap without lure	10.00	2.50 ±1.29 (1.73) [cd]	12.00	3.00 ±2.45 (1.87) [c]
F test		*	-	*
SEm±		0.80	-	1.11
CD (p≤ 0.05)		2.34	-	3.27

*Traps were placed in castor field (GCH-4) at early reproductive phase (65 days after sown) on first week of October 2015 and checked weekly until second week of January 2016; lures were changed after 60 days of trap placement. * Significant at 0.05 level; Means followed by same letter are not significantly different (P>0.05) by LSD; figures in parentheses are square root transformed values i.e.,* $\sqrt{X + 0.5}$.

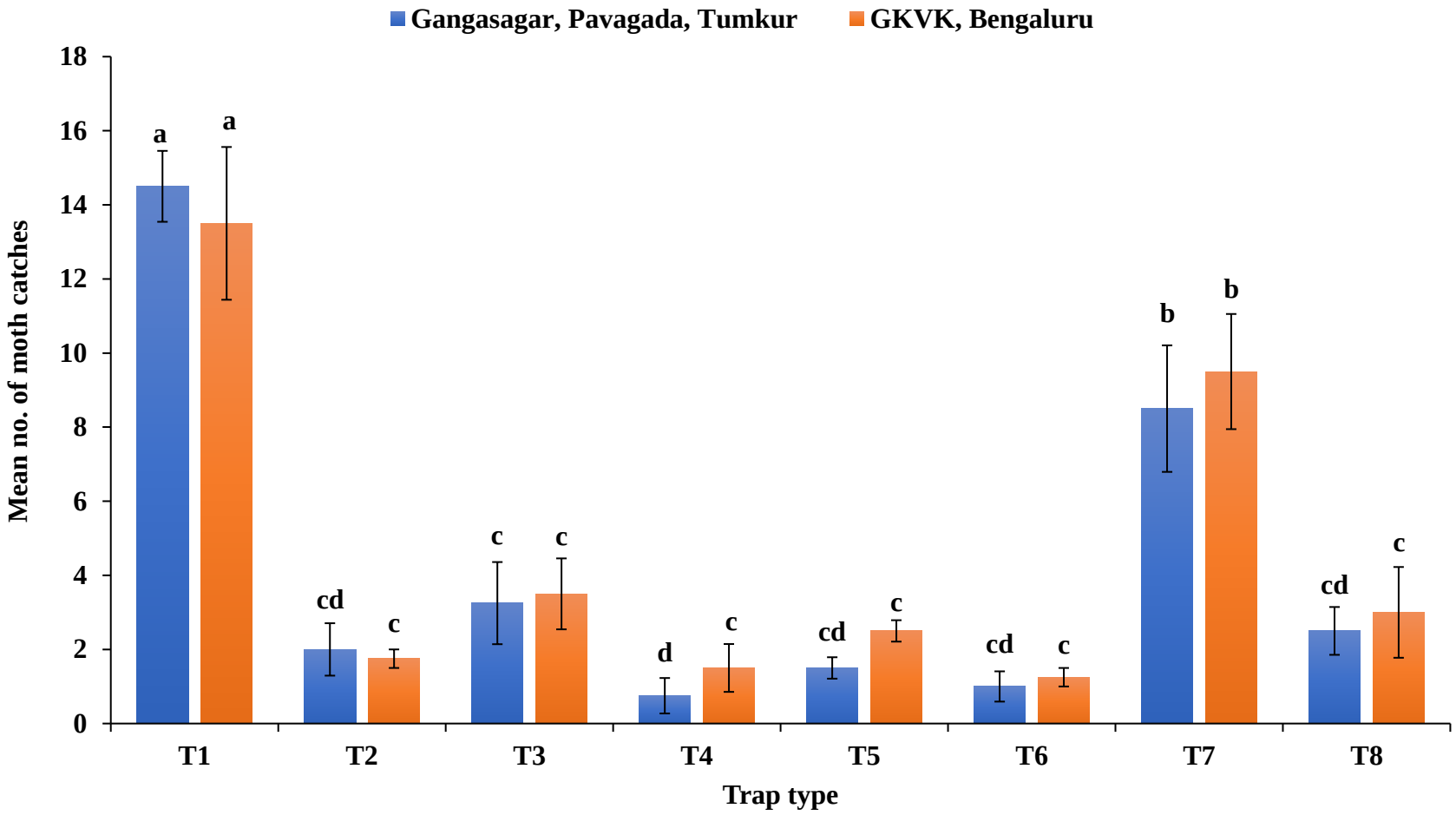

Fig. 20. Catches of *C. punctiferalis* moths in different types of traps.

T1- Delta trap with lure, T2- Delta trap without lure, T3- Cross-vane trap with lure, T4- Cross-vane trap without lure, T5- Funnel trap with lure, T6- Funnel trap without lure, T7- Water trap with lure, T8- Water trap without lure; Bars represent means ±standard error; and means followed by the different lower-case letters in every bar are significantly different (LSD test, P<0.05).

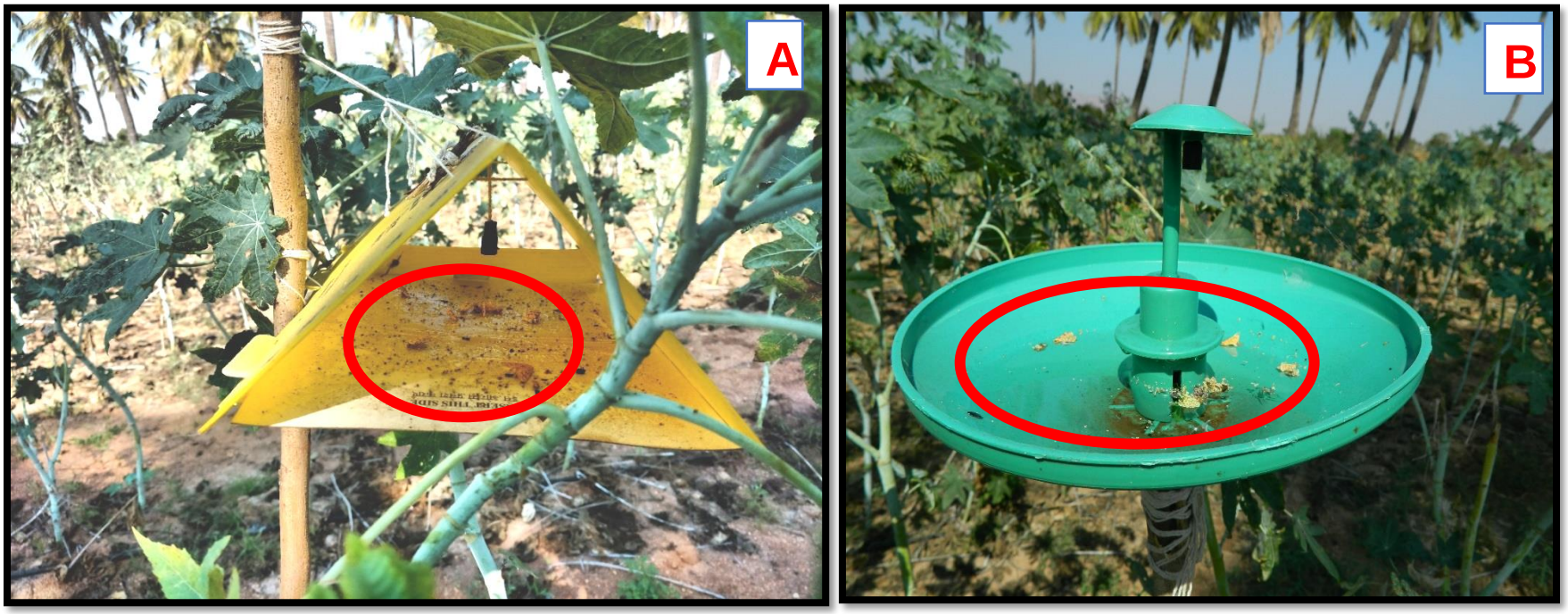

Plate 20. Moth catches in trap. A: Yellow delta trap, B: Water trap in castor field, Pavagada, Tumkur

4.4 Sex Pheromone trapping plan

4.4.1 Trap colour

The colour and shape of traps, in short, the design of the trap also matters in effectively trapping moths. Four colours of delta traps were tested for efficacy against *C. punctiferalis* moths for every colour trap a control was run which was without lure (Table 75). The yellow coloured delta trap attracted and trapped a maximum number of moths (43 moths/4 traps, average=10.75 moths/ trap). The red coloured delta traps (22 moths/4 traps, average=5.50 moths/ trap) proved effective next only to the yellow coloured delta trap in attracting *C. punctiferalis* moths. These results suggested that yellow and red coloured traps are attractive to *C. punctiferalis* moths. The wavelength of yellow and red colour ranges from ~570nm and 650nm, respectively. The wavelength of colour light for optimal perception by moths also closely match with the wavelength band with yellow and red colour. The green delta traps (7 moths/ 4 traps, average= 1.75/trap) and white delta traps (7 moths/ 4 traps, average= 1.75/trap) with lure were not effective in trapping *C. punctiferalis* moths (Table 75 and Fig. 21).

When the data were subjected to ANOVA statistical analysis followed by LSD test (*P>0.05*), it indicated statistical significant differences between yellow and red delta traps and the green and white delta trap. The yellow and red trap proved statistically superior over green and white delta traps in attracting *C. punctiferalis* moths (Table 75).

Four colours of delta traps were tested for efficacy against *C. punctiferalis* moths for every colour trap a control was run which was without lure. It was found that the yellow and red traps proved statistically superior over green and white delta traps in attracting *C. punctiferalis* moths. Generally, the range of light perception falls between 495-750nm. Since the colour of the trap is yellow, the moths were quickly orientated and make directed flight towards the traps. Insects that are attracted to these yellowish devices (Shimoda and Honda, 2013). Taha *et al.* (2012) showed that the mean catch of *T. absoluta* moths per trap/ observation were (35.88, 17.58, 12.33 and 10.71) for trap colors (red, blue, green, and yellow), respectively. However, the correlation of traps reflectance data and their relative

capture of such moths showed that the red sticky traps with 39.7% reflection at dominant wavelength of 612.1nm caught more moths than blue, green and yellow traps.

4.4.2 Trap height

The height at which the traps must be placed is crucially important for attracting maximum number of *C. punctiferalis* moths. Four selected heights were evaluated for attracting *C. punctiferalis* moths and data is presented in Table 76. Delta traps set at crop canopy level (Plant height about 3-4.5 m) proved effective (39 moths/4 traps, an average =7.80 moths/trap) in trapping. The next height was below the crop canopy level (0.3m), but it attracted only 14 moths/traps, an average=2.80 moths/trap. The traps set at canopy level were statistically superior to those set at below canopy level (at ZAHRS, Babbur farm, Hiryur, SEm= 0.71, CD ($p \leq 0.05$) =2.18 and at GKVK, SEm= 0.85, CD ($p \leq 0.05$) =2.61). The optimum height for the trap was tested at two locations, one at Hiriyur and second at GKVK. Consistent results were obtained at both the locations and delta traps set at canopy level in castor field proved most effective in attracting moths.

Four selected heights were evaluated for attraction *C. punctiferalis* moths and found that delta traps set at canopy level in castor field proved most effective in attracting moths. A comparative study was conducted on the efficiency of different doses, lure color, number and types, as well as hanging height of traps on capture of *C. punctiferalis.* The results showed that water barrel trap with a lure of zhongjie company and hung it in the middle of crown could reach to the best trapping effect (Ren and Guo, 2015). When traps were stacked at different heights at one site, more *C. ignefusalis* moths were caught in traps at heights of 0.10-0.50 m than at 1.30 and 2.0 m above ground level, regardless of crop height (Youm and Beevor, 1995). Present study revealed that more number of *C. punctiferalis* moth catches in yellow delta trap baited with pheromone lure compared to earlier workers of *Conogethes* moth due to timing of trap placement, trap type, colour of the trap and height at which trap were placed had significant role in attracting moths.

Table 75. Catches of male *C. punctiferalis* moths on castor in delta traps at ZAHRS, Babbur farm, Hiryur in castor field

Colour type	Total number of moths trapped/4 traps	Mean ± SD
Yellow delta trap with lure	43	10.75 ±8.92 (3.35) [a]
Yellow delta trap without lure	6	1.50 ±1.19 (1.41) [bc]
Green delta trap with lure	7	1.75 ±0.63 (1.50) [bc]
Green delta trap without lure	1	0.25 ±0.25 (0.87) [c]
White delta trap with lure	7	1.75 ±0.75 (1.50) [bc]
White delta trap without lure	2	0.5 ±0.29 1.00) [c]
Red delta trap) with lure	22	5.50 ±1.85 (2.45) [b]
Red delta trap without lure	4	1 ±0.71 1.22) [bc]
F-test		*
SEm±		1.70
CD (p≤ 0.05)		4.99

*Traps were placed in castor field (GCH-4) at early reproductive phase (55-65 days after sown) on first week of October 2016 and checked weekly until second week of February 2017; lures were changed after 60 days of trap placement; * Significant at 0.05 level; Means followed by same letters are not significantly different (P>0.05) by LSD; figures in parentheses are square root transformed values i.e.,* $\sqrt{X + 0.5}$.

Table 76. Catches of male *C. punctiferalis* moths on castor in yellow delta traps at different heights

Different heights	ZAHRS, Babbur farm, Hiryur		GKVK, Bengaluru	
	Total number of moths trapped/4 traps	Mean ± SD	Total number of moths trapped/4 traps	Mean ± SD
0.3m above the crop canopy level	4.00	0.80 ± 0.45 (1.14) [b]	6.00	1.20 ± 0.84 (1.45) [c]
0.1m above the crop canopy level	7.00	1.40 ± 0.55 (1.38) [b]	8.00	1.60 ± 0.55 (3.18) [bc]
Equal to crop canopy level	39.00	7.80 ± 2.77 (2.88) [a]	48.00	9.60 ± 3.65 (2.12) [a]
0.3m below the crop canopy level	14.00	2.80 ± 1.48 (1.82) [c]	20.00	4.00 ± 1.58 (2.14) [b]
F-test		*		*
SEm±		0.71		0.85
CD (p≤ 0.05)		2.18		2.61

** Significant at 0.05 level; Means followed by same letter are not significantly different (P>0.05) by LSD; figures in parentheses are square root transformed values i.e.,* $\sqrt{X + 0.5}$.

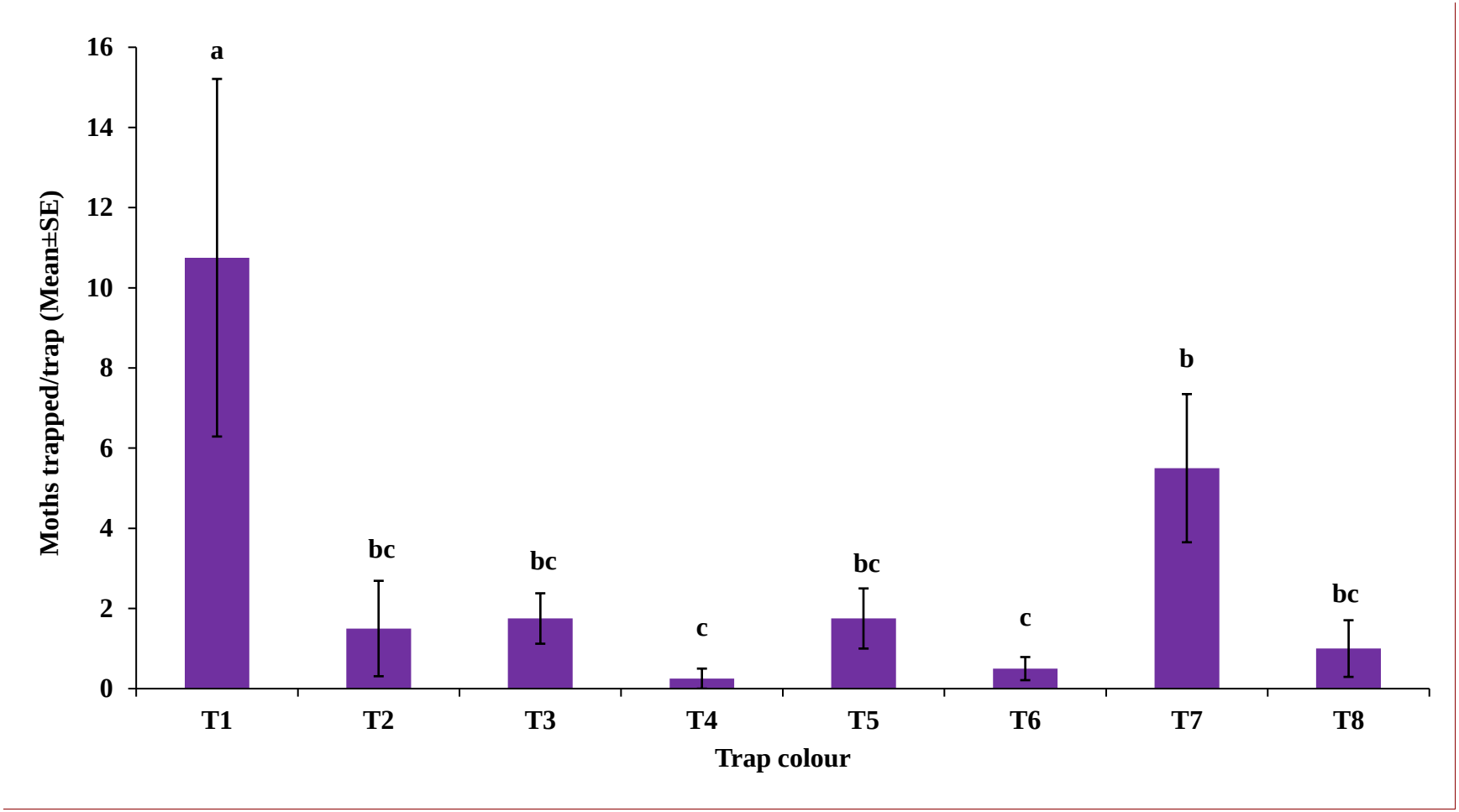

Fig. 21. Catches of *C. punctiferalis* moths in different coloured delta traps

T1- Yellow delta trap with lure, T2- Yellow delta trap without lure, T3- Green delta trap with lure, T4- Green delta trap without lure, T5- White delta trap with lure, T6- White delta trap without lure, T7- Red delta trap with lure, T8- Red delta trap without lure; Bars represent means ±standard error; and means followed by the different lower-case letters in every bar are significantly different (LSD test, P<0.05).

4.4.3 Viability / longevity of pheromone component in the field exposed lure and correlation with weather parameters

Residue analysis of pheromone components when lure exposed in castor fields at ZAHRS, Babbur farm, Hiryur revealed that the pheromone released rate varied across 60 days; the initial quantity of release (after 15 days) was 68.33 per cent, later the rate of release was reduced to 2, 8, and 10 per cent for 30, 45 and 60 days, respectively. However, pheromone lures of rubber septa loaded with female sex pheromone (3 mg) emitting the active ingredient at an average of < 1. 83 mg/day. This would be enough to trap male moths for a period of 60 days after installation. Since the active reproductive duration of castor crop in the field varies between 60-75 days, one lure per delta trap is enough to attract *C. punctiferalis* adults for mass trapping plans (Table 77 and Fig. 22).

The data on release rate of *C. punctiferalis* pheromone components and mean weather parameters were subjected to simple correlation analysis (Table 78). The progressive quantity released was positively correlated with maximum temperature (r= 0.113), wind speed (r= 0.183) and evaporation (r= 0.849), whereas, negatively influenced by minimum temperature (r= -0.465), morning relative humidity (r= -0.968) and afternoon RH (r= -0.783). The influence of these factors was statistically significant (Table 78). It may be due to the combined effects of the chosen weather parameters with the release rate of pheromone. When the data was subjected to linear regression analysis it revealed that, 100 per cent (R^2= 1.00) lure release was influenced by factors other than those chosen, or it might be a combination of all the chosen weather parameters with equation as follows.

Y (Progressive quantity release of pheromone) = $-24.37+ 0.60X_1 - 0.449X_2 - 0.029X_3 - 0.163X_4 – 2.099X_5 - 0.33X_6 +2.38X_7$: $\boldsymbol{R^2=1.00.}$

Table 77. Release rate of *C. punctiferalis* pheromone components in field exposed lures, ZAHRS, Babbur farm, Hiryur, 2017-18

Date	Duration of field exposure (days)	Progressive quantity released (mg)	Average quantity remained (mg)	Proportion of pheromone released during the period (%)	Proportion of pheromone remaining over the period (%)	Number of moth catches/ 5 traps	Mean number of moth catches
10-11-2017	0	0.00	3.00	0.00	100.00	0.00	0.00
25-11-2017	15	2.05	0.95	68.33	31.67	42.00	8.40
10-12-2017	30	2.11	0.89	70.33	29.67	34.00	5.80
25-12-2017	45	2.35	0.65	78.33	21.67	19.00	3.60
10-01-2018	60	2.65	0.35	88.33	11.67	9.00	1.80

*** Standard loading = 3 mg/lure; n=5 lures used for residue analysis*

Table 78. Relationship between the release rate of *C. punctiferalis* pheromone components in field and meteorological parameters, ZAHRS, Babbur farm, Hiryur, 2017-18

Variables		Temperature (^{0}C)		Relative humidity (%)		Windspeed (km/hrs.)	Sunshine (hrs.)	Evaporation (mm)
		Max.	Min.	Morning	Afternoon			
Progressive quantity released (mg)		0.113 NS	-0.465*	-0.968**	-0.783**	0.183 NS	-0.079 NS	0.849**
Temperature (^{0}C)	**Max. (X_1)**	1	0.276 NS	-0.041 NS	-0.021NS	-0.703**	-0.304 NS	-0.027 NS
	Min. (X_2)		1	0.533**	0.891**	0.028 NS	-0.841**	-0.846**
Relative humidity (%)	**Morning (X_3)**			1	0.825**	-0.081 NS	0.002 NS	-0.895**
	Afternoon(X_4)				1	0.111 NS	-0.536**	-0.989**
Wind Speed (km/hr.) (X_5)						1	-0.176 NS	-0.030 NS
Sunshine (hrs.) (X_6)							1	0.435*
Evaporation (mm) (X_7)								1

**- Significant at 0.05 level; **- Significant at 0.01 level (2-tailed); NS- Non significant*

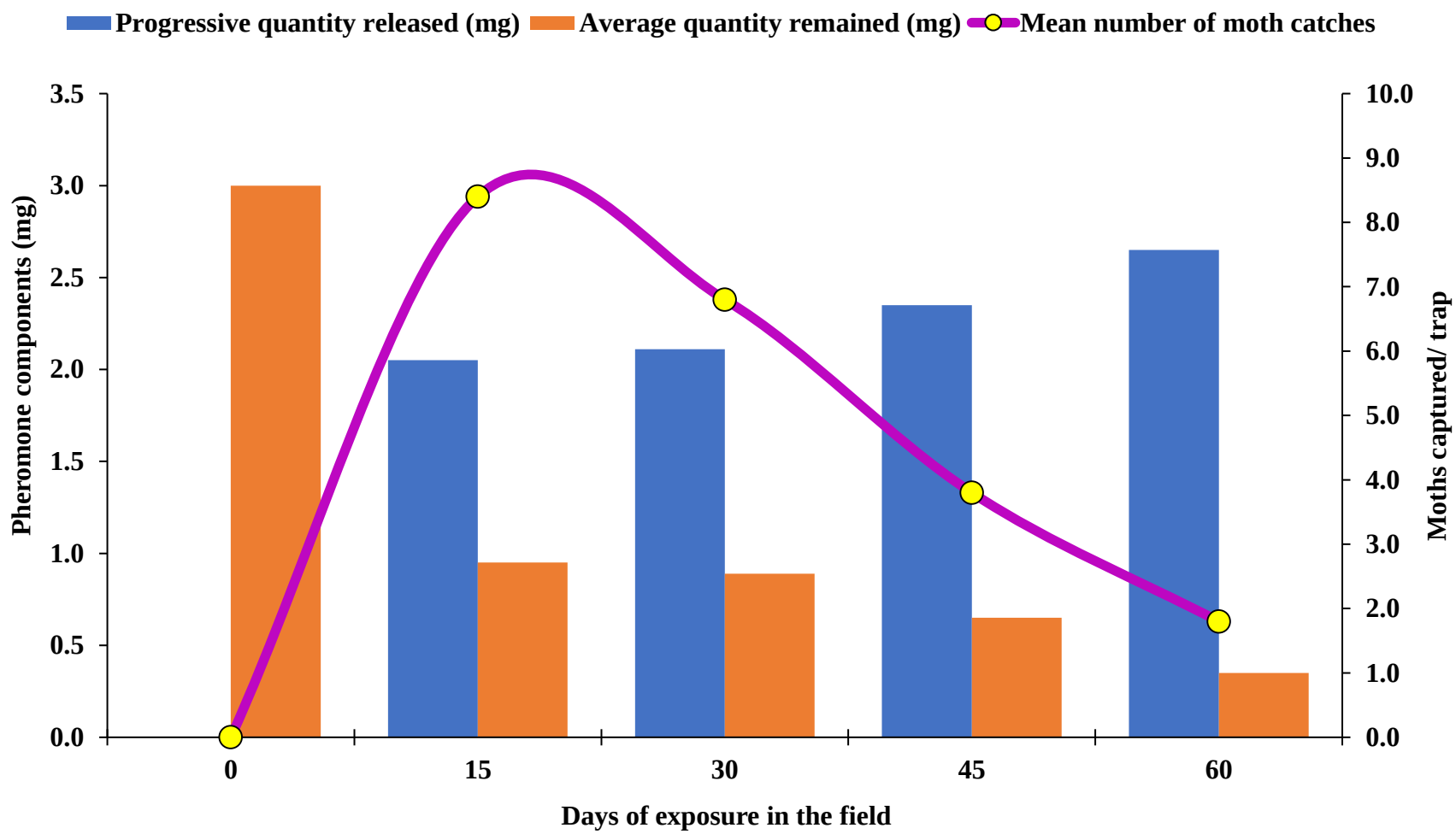

Fig. 22. Pheromone release rate in the field exposed lures, ZAHRS, Babbur farm, Hiryur, 2017-18.

Standard loading = 3 mg/lure; n=5 lures used for residue analysis and moths catches in yellow delta trap

V SUMMARY

The results of the investigation on "Standardization of mass rearing technique and field evaluation of pheromone of shoot and capsule borer, *Conogethes* spp (Lepidoptera: Crambidae) on selected host plants" are summarized here under.

To facilitate mass rearing of two important species of the shoot and capsule borer viz., cardamom shoot and fruit borer, *C. sahyadriensis* and castor shoot and fruit borer, *C. punctiferalis* in South India. Field observations in cardamom and castor fields on seasonal incidence of the borer were recorded. Observations on *C. sahyadriensis* at two cardamom plantations in Mudigere, Chikkamagalur revealed that maximum infestation on cardamom shoot was recorded during May and on capsule during October-November. The activity of the pests in cardamom plantations began from March and lasted till January the next year. The activity of *C. sahyadriensis* coincided with active tillering and capsule formation and humid weather conditions. Observations on *C. sahyadriensis* at three ginger plantations in Hassan, Shivamogga and Kodagu revealed that maximum borer infestation was recorded during September – October.

Field observations on seasonal incidence of *C. punctiferalis* at two castor fields in ZAHRS, Babbur farm, Hiryur, Chitradurga and Dryland Agriculture, UAS, GKVK, Bengaluru revealed that maximum infestation on castor shoot and capsule was recorded during November-December. The activity of *C. punctiferalis* in castor field began from September and lasted till March of the next year. The activity of *C. punctiferalis* coincided with tender shoots, inflorescence and tender capsule formation and humid weather conditions.

Results of field observations on seasonal incidence revealed that October and November for *C. sahyadriensis* and November and December for *C. punctiferalis* were suitable, when a large number of different life stages of these two species were available under natural conditions. This information is important to facilitate mass rearing of these two species under laboratory conditions, both as natural host-plant and artificial diet, and to develop eco-friendly management strategies against these two species.

C. punctiferalis and *C. sahyadriensis* were reared simultaneously on four types of diets *viz*., Diet-A, Diet-B, Diet-C with different compositions and Diet-D (natural food). The total developmental periods of castor borer, *C. punctiferalis* were significantly shorter (40.12 days) on diet-A than on other diets. The data revealed that among the four types of diets, Diet-A consisting castor as plant was found the most suitable for growth and development of *C. punctiferalis*. Diet- B was unsuitable for the growth and development of *C. punctiferalis* as cardamom may not be in the innate host range of castor borer.

Among different diets, the total developmental periods of cardamom borer, *C. sahyadriensis* were significantly shorter (38.66 days) on diet-B. The data revealed that Diet-B consisting cardamom as constituent plant was found the most suitable for growth and development of *C. sahyadriensis*. Diet-A was unsuitable for the growth and development of *C. sahyadriensis.* Results of present investigations revealed that *C. punctiferalis* and *C. sahyadriensis* require artificial diets with respective plant powders incorporated into the diet. Artificial diets with the same constituents were not suitable for the mass multiplication of both the species of *Conogethes*.

The diets F_b and diet-J_b were the most preferred diets for *C. punctiferalis* and *C. sahyadriensis*, respectively, as it contains 35g/ml of casein and recorded the highest percentage of larval survival, pupation, male and female pupal weight, fecundity and the shortest life cycle compared to other diets. The diets F_c and diet-J_c contained Vit-E capsule (1gm/ml) were found maximum number of viable eggs in *C. punctiferalis* and *C. sahyadriensis*, respectively.

The diets F_d and diet-J_d were the most preferred diets for *C. punctiferalis* and *C. sahyadriensis*, respectively, as it contained appropriate quantity of anti-microbial ingredients *viz*., sorbic acid (1g/ml), Methyl parahydroxy benzoate (2g/ml) and streptomycin sulphate (0.5g/ml) and recorded the higher percentage of fecundity and survivability compared to other diets. This is the first time that an artificial diet for a species of *Conogethes* has been perfected for four generations.

Pheromone traps were evaluated for eco-friendly management of castor shoot and capsule borer during 2016-18 at Gangasagar, Pavgada, Tumkur (Dist.), ZAHRS, Babbur farm, Hiryur, Chitradurga (Dist.) and Dryland Agricultural Research Station, GKVK, Bengaluru. Among four types of traps (delta, water, funnel and cross-vane trap) tested, delta trap with lure (contained (*E*)-10-hexadecenal (E10-16:Ald), (*Z*)-10-hexadecenal (Z10-16:Ald) and hexadecenal (16:Ald) at 100:8:16) proved the most effective for trapping male *C. punctiferalis* moths and it was statistically significant in trapping moths compared to other traps.

Studies on standardization of trapping technique indicated that all the traps baited with pheromone lures had significantly higher catches over the traps without pheromone lures at both Bangalore and Tumkur. The delta traps installed at the crop canopy level were found more attractive over rest of the heights. Studies on trap colour indicated that the delta trap with yellow colour was found attracting maximum number of moths than other types of traps. The wavelength of colour light optimal perception by moths also closely match with the wavelength band yellow colour.

Studies on moth catches with abiotic factors at Dryland Agricultural Research Station, GKVK, Bengaluru and ZAHRS, Babbur farm, Hiryur revealed that maximum number of moths trapped were recorded during 46^{th} to 48^{th} standard week and then the moth catches declined gradually. The minimum number of moths was recorded during 7^{th} standard week. However, the influence of temperature and relative humidity on trap catches was found significant, while moth catches were negatively influenced by sunshine hours, wind speed and rainfall.

Residue analysis of pheromone components when exposed in castor field at ZAHRS, Babbur farm, Hiryur in field exposed lures, revealed that the pheromone release rate varied across 60 days. The lures loaded with female sex pheromone (3 mg) emitted the active ingredient at an average of <1. 83 mg/day. Influence of the weather parameters was found significant with the progressive quantity released. The progressive quantity released exerted a highly significant positive association with maximum temperature, windspeed and evaporation whereas, negatively influenced by minimum temperature and relative

humidity. This is one of its first kind of studies that has standardized trapping plan for *Conogethes* spp under field conditions and laboratory conditions.

Future line of work

1. Gut physiological studies of *C. punctiferalis* and *C. sahyadriensis* reared on meridic diets.
2. Standardization of pheromone blend for *C. sahyadriensis*
3. Standardization and validation of pheromone trapping plan for *C. sahyadriensis* in Zingiberaceous cropping system.
4. Mating disruption studies in *C. punctiferalis* and *C. sahyadriensis.*
5. Large scale field testing of mass trapping, trapping density and attractiveness of lure as a stand-alone method as a pest management tool for *Conogethes* spp.

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*Original not seen.

APPENDIX I

Weather parameters of Zonal Agricultural and Horticultural Research Station (ZAHRS), Mudigere, 2016

Month	Fortnight	Temperature (^{O}C)		Relative humidity (%)		Rain fall (mm) (X_5)	Sunshine (hrs.) (X_6)
		Max. (X_1)	Min. (X_2)	Morning (X_3)	Evening (X_4)		
January	I	28.80	20.13	80.40	70.60	0.00	7.37
	II	29.06	19.31	83.13	72.75	0.13	7.69
February	I	31.40	20.07	81.87	67.60	0.00	8.33
	II	31.57	20.43	83.57	68.79	0.00	8.07
March	I	32.60	20.87	83.60	71.67	0.00	8.97
	II	33.00	21.75	84.00	72.65	0.00	9.22
April	I	33.27	23.20	83.87	75.80	0.25	8.87
	II	34.27	23.27	82.60	74.40	1.14	9.33
May	I	33.60	20.07	84.27	76.47	5.40	8.77
	II	29.63	19.88	84.88	76.13	3.38	7.00
June	I	27.33	20.67	85.53	79.20	5.41	1.77
	II	25.40	20.67	85.33	79.87	16.43	0.50
July	I	25.40	20.33	85.67	79.80	27.85	0.23
	II	25.31	20.31	86.06	80.06	8.75	0.28
August	I	25.27	20.27	85.13	80.47	9.79	0.00
	II	25.81	20.69	85.38	80.19	3.40	0.50
September	I	24.53	20.20	85.20	79.87	2.47	2.83
	II	24.60	20.07	85.13	79.33	2.58	3.20
October	I	28.27	19.80	85.20	77.60	2.56	5.07
	II	29.75	20.31	85.19	78.44	0.00	8.19
November	I	29.67	20.20	85.33	75.00	3.27	8.13
	II	29.73	19.93	83.47	71.00	0.00	8.47
December	I	27.60	19.53	81.53	73.87	0.97	8.50
	II	29.75	20.50	80.69	68.69	0.00	9.19

APPENDIX II

Weather parameters of Zonal Agricultural and Horticultural Research Station (ZAHRS), Mudigere, 2017

Month	Fortnight	Temperature (^{O}C)		Relative humidity (%)		Rain fall (mm)	Sunshine (hrs.)
		Max. (X_1)	Min. (X_2)	Morning (X_3)	Evening (X_4)	X_5	X_6
January	I	29.27	20.20	84.93	71.80	0.00	8.10
	II	28.81	19.94	84.94	72.38	0.13	8.13
February	I	29.47	19.93	80.80	70.53	0.00	9.00
	II	30.00	19.85	80.00	70.56	0.00	9.11
March	I	32.60	20.87	83.60	71.67	0.00	8.27
	II	33.00	21.75	84.00	72.56	2.16	7.84
April	I	33.27	23.20	75.80	33.27	2.58	6.90
	II	34.27	23.27	74.40	34.27	0.15	8.33
May	I	33.60	20.07	84.27	76.47	5.56	2.07
	II	29.63	19.88	84.88	76.13	6.51	4.34
June	I	27.33	20.67	85.53	79.20	8.65	0.00
	II	25.40	20.67	85.33	79.87	11.85	0.00
July	I	25.40	20.33	85.67	79.80	5.61	0.00
	II	25.31	20.31	86.06	80.06	20.66	0.00
August	I	25.27	20.27	85.13	80.47	6.17	1.00
	II	25.81	20.69	85.38	80.19	18.98	0.28
September	I	24.53	20.20	85.20	79.87	3.62	1.63
	II	24.60	20.07	85.13	79.33	9.91	0.47
October	I	28.27	19.80	85.20	77.60	4.23	0.47
	II	29.75	20.31	85.19	78.44	0.25	6.00
November	I	29.67	20.20	85.33	75.00	0.80	7.00
	II	29.73	19.93	83.47	71.00	0.07	5.83
December	I	26.67	18.93	84.07	75.80	0.00	6.50
	II	28.31	18.25	84.38	74.56	0.00	6.19

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Artificial Diet for Rearing of *Conogethes punctiferalis* Guenee (Lepidoptera : Crambidae)

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Abstract

This experiment was conducted to develop an artificial diet for rearing of castor shoot and capsule borer, *Conogethes punctiferalis* Guenee under laboratory conditions. The results revealed that artificial diet-1 yielded a larval survival rate of 95.46 per cent, mean pupal weights of 61.15 mg for females and 50.24 mg for males, fecundity rate of 39.02 eggs per females and took shortest period to complete the life cycle (31.48d). These outcomes indicated that *C. punctiferalis* adapted well to the artificial diet and successive rearing conditions. The diet could serve as a viable alternative to the natural host plants for consecutive rearing of the insects.

Keywords : artificial diet, *Conogethes punctiferalis*

The castor shoot and capsule borer, commonly called as yellow peach moth *Conogethes punctiferalis* Guenee (Lepidoptera : Crambidae) is major insect pest of castor, *Ricinus communis* L. and is widely distributed in south and East Asia, Australia, New Zealand and Papua New Guinea (CAB International, 2011). The larva of *C. punctiferalis* is highly destructive and typically polyphagous attacking more than 120 wild and cultivated plants *viz.*, peach, apple, pine trees, chestnut, durian, citrus, papaya, cardamom, ginger, egg plant, sunflower, maize and forestry crops (Lu, *et al.*, 2010; Li *et al.,* 2015) and cause a huge yield loss of more than 55 per cent in castor (Ganesha, 2012). Effective management of *C. punctiferalis,* often relies on sound integrated pest management (IPM) strategy. To develop and improve IPM strategies, studies were carried out to understand its bio-ecology, physiology and toxicology. One of the pre-requisites for conducting these studies is availability of a large number of healthy eggs, uniformly developed larvae, pupae and adults for testing. Hence, a successful artificial diet for rearing *C. punctiferalis* in laboratory is highly desirable to facilitate studies for developing sound IPM programmes.

The development of artificial diets, pioneered by Vanderzant *et al.* (1962), facilitated the continuous production of insects. Since then, many species of lepidopterans, coleopterans and dipterans have been successfully reared under controlled laboratory conditions (Gupta *et al.,* 2005). The rearing of *C. punctiferalis* on meridic diets proposed by Honda *et al.* (1979) suggested that colonies fed on these diets had a larger variation in the development duration than the colonies fed on natural host plant materials. However, they still could not produced large number of uniform larvae due to low larval survival and adult emergence, insufficient nutrition of diets *etc*. Considering the sparse information on artificial diet for mass-rearing *C. punctiferalis,* the present study on artificial diet was planned.

Material and Methods

Insects: The initial *C. punctiferalis* population was established with a collection of larvae from castor fields at the Dryland Research Station, University of Agricultural Sciences, GKVK, Bengaluru (13^0 05" N, 77^0 34" E with 924m MSL), Karnataka, India during 2015-16 and the borer population was maintained on fresh castor for one generation. The stock borer culture was held in laboratory under the 26±1^{0}C, 70-80 per cent relative humidity and a photo period of 16 : 8 h light : dark.

Artificial diets: The semi-synthetic diet formulated for *Conogethes* sp. (Ambanna, 2014) was used as a starting medium for preparation of meridic diet for castor shoot and capsule borer and the diet was modified by the addition of young capsule powder as a token stimuli and variation of casein amount as mentioned below :

1. Artificial diet 1 (Castor young capsule based meridic diet) - Castor leaf powder as a token stimuli.

2. Artificial diet 2 (Plain meridic diet) - without the addition of any capsule powder and reduced amount of casein.
3. Natural diet- castor capsule as a control.

The ingredients for the diets were divided into three parts (A, B&C) as shown in Table I. Part A: The ingredients were weighed and kept separately before mixing. Castor young capsule powder was homogenized with 400 ml of water in a blender. The homogeneous mixture was mixed with soybean powder, casein, yeast extract powder and sucrose in a stainless steel pot. The mixture was autoclaved for 30 min at 125^{0}C. Part B: Agar with 300 ml of distilled water was heated to boiling to dissolve the agar completely. At this point, this part was poured into part A, blended for 3min, and allowed to cool for future use. Part C: The weighed ascorbic acid, Wesson's salt, sorbic acid, multivitamin multimineral capsules, vitamin E, methyl parahydroxy benzoate and streptomycin sulphate were dissolved in 75 ml of distilled water. The solution was added to the mixture of part A and B and blended for 3min. Before the mixture became cold, the diet was poured plastic vials (5 x 4 cm) filling 3/4th the volulme and sealed with plastic cling cap, and the diet was allowed to solidify to room temperature.

Rearing procedure: To compare two formulated artificial diets with the natural diet, 30 neonate larvae obtained from stock culture were transferred into each screw capped plastic vial (5 x 4 cm) using a fine hair brush. The vials were covered with a transparent plastic lid with small holes for ventilation. From the 2nd to 5th generations, the population was solely reared on the artificial diets. Larval survival and development were checked daily. When the larvae reached penultimate stage, the cloth (100 x 75mm) was placed in the diet blocks to provide pupation sites. After pupation, the newly formed pupae were collected from rearing vials, sexed, numbered, weighed and placed in plastic boxes (15 x 6 cm) for adult emergence. Pupal survival, duration and adult emergence were observed daily. Each treatment was replicated five times with a total of 150 larvae per diet treatment per generation.

For each diet treatment, newly emerged adults (1:1; female: male) were paired and released into the ventilated glass cages (60 x 60 x 60 cm) containing castor inflorescence (raceme). The panicle and young capsules were placed in 500 ml conical flask with water to mimic natural ambience and fed with 10 per cent honey solution soaked in cotton swabs/wads, black cloth for mating and oviposition. Eggs deposited on plant parts, cotton swabs and black cloth were collected and counted. Collection of eggs was continued until female in the cage. Adult longevity also was recorded. Eggs were counted under a microscope (Nikon SMZ25, 1x, WD: 60) and placed into the petri dishes (8cm). The number of hatched F_1 larvae was counted daily.

Castor panicle with flowers and young capsules collected from castor field in Dryland Research Station, University of Agricultural Sciences, GKVK, Bengaluru was used as a control diet treatment. Rearing conditions and experimental procedures were the same as that of the artificial diet treatments. The total life cycle mean of four generations were cumulated for statistical analysis.

Statistical analysis: The biological parameters including incubation period, larval development, larval survival (ratio of larvae to pupae), pupal duration, weight and survival rate (ratio of pupae to adult), pre-oviposition duration and egg hatchability over mean four generations were recorded, and compared among the diet treatments using analysis of variance (ANOVA). Significant differences of mean of four generations in different treatments (diets) were tested. All analysis was performed with SPSS 16.0 statistical software. The life table parameters were calculated for each diet using Jack knife analysis; each parameter was compared at 95 per cent confidence interval.

RESULTS AND DISCUSSION

The data on the number of days required to complete each insect stage is presented in Fig. 1. Duration of the larval (16.37 d) and pupal stages (7.12 d) on the artificial diet-1 was shorter than the artificial diet-2 and the natural diet. There was no

TABLE I

Composition of ingredients in the artificial diet used to rear C. punctiferalis

Parts	Ingredient	Artificial diet 1 (Quantity)	Artificial diet 2 Quantity	Functions
A	Soybean powder (Commercially available)	130gm	100 gm	As a main ingredient/carrier
	Castor leaf powder (Locally prepared)	80 gm	-	As a token stimuli to initiate and maintain continuous feeding
	Yeast powder (RM027-500G, HiMedia Lab. Pvt Ltd.)	25gm	25gm	Source of protein and vitamin
	Casein (GRM497-500G, HiMedia Lab. Pvt Ltd.)	20gm	10gm	A protein source which provides amino acids and Carbohydrates for tissues
	Sucrose (GRM134-500G, HiMedia Lab. Pvt Ltd.)	15 gm	15 gm	As a source of sugar
	Distilled water	400ml	400ml	As a solvent for diet ingredients
B	Agar-agar (GRM666-500G, HiMedia Lab. Pvt Ltd.)	15gm	15gm	Solidifying agent
	Distilled water	300ml	300ml	As solvent
C	Ascorbic acid (PCT0207-100G, HiMedia Lab. Pvt Ltd.)	3gm	3gm	Normal growth and development, egg hatching and pupal survives
	Wesson's salt mixture (TS1100, HiMedia Lab. Pvt Ltd.)	1.5gm	1.5gm	As source of salt required to maintain membrane structure and function
	Sorbic acid (FD236-0.200g, HiMedia Lab. Pvt Ltd.)	1gm	1gm	As preservative so that the diet does not deteriorate
	Multivitamin multimineral capsules (BECADEXAMIN, GlaxoSmithKiline. Pvt Ltd.)	2 nos.	2 nos.	SuppliesVitamins
	Methyle parahydroxy benzoate (GRM1291-500G,	2 gm	2 gm	As food and flovor ingredient, stimulant
	Strepomycine sulphate (CMS220-5G, HiMedia Lab. Pvt Ltd.)	0.5gm	0.5gm	As an antibiotic for reducing microbial contamination
	Vit. E capsule USP 400mg (Evion 400, MERCK Ltd.)	2 nos.	2 nos.	As a source of vitamins for reproduction

Values in the table show the quantities in 1000g of artificial diets

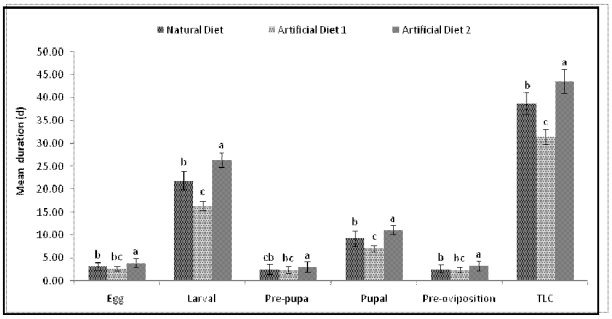

Fig.1: Duration of developmental stages (egg to adult, N=30) of *Conogethes punctiferalis* reared onarticifial diets (1 and 2) and natural host. TLC-total life cycle. Bars represent Means±SE; significant differences among three host plants are indicated by letters over each bar (*P>0.05*, LSD test).

significant difference in pre-oviposition period among the diets. On artificial diet-2, the insect took longest period to complete life cycle (43.56±2.60 d) and it was statistically significant from the duration required to complete the total life cycle on artificial diet-1 and natural diet. Artificial diet-1, wherein castor capsule powder was incorporated as on ingredient, the insect took minimum number of days to complete the life cycle (31.48±1.50 d). In natural diet, the duration required was in between the two artificial diets (38.78±2.34 d). The total life cycle of *C. punctiferalis* reared on artificial diet-1 was shorter than the artificial diet-2 and the natural diet over four generations (Fig. 2). Therefore, for a balanced diet and optimum yield of quality insects. The artificial diet should be inclusive of both essential and non-essential ingredients. Further, the texture and structure of the artificial diet should be attractive, so that the insect feeding on artificial diet has stimulating effect. Li *et al.* (2015) reported that a generation developmental time for *C. punctiferalis* on artificial diet ranged from 42.4 d to 63.3 d.

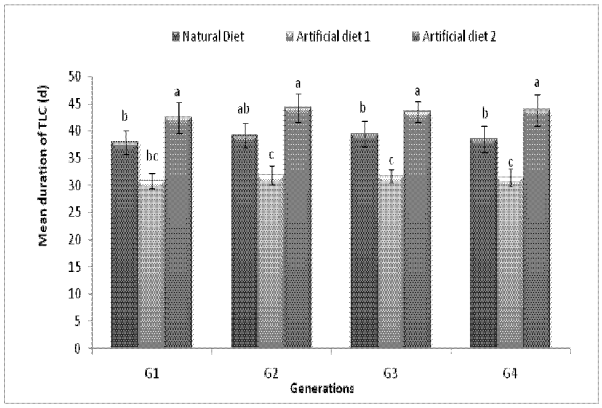

Fig.2: Total life cycle of *C. punctiferalis* reared on three diets *viz.*, artificial diet-1, artificial diet-2 and natural diet over four successive generations. Generations (G1, G2, G3 and 4); Bars represent Means ± SE; significant differences among three diets over four generations were indicated by letters over each bar (P>0.05, LSD test).

Data on quantitative and qualitative parameters of *C. punctiferalis* reared on artificial diets is presented in Table II. Insect fed with artificial diet-1 laid maximum number of eggs (39.02±1.67). This was statistically significant and higher than the number of egg laid by females reared on natural and artificial diet-2. A similar trend in values with respect to pupal weight and adult longevity was observed (Table II).

TABLE II

Pupal weight, adult longevity and fecundity of Conogethes punctiferalis *reared on articifial and natural diets*

Diets	Pupal Weight (mg)		Adult Longevity (d)		Mean** no. eggs per
	Female	Male	Female	Male	Female
Natural Diet	53.27±0.47b	40.72±0.83b	8.23±0.30b	7.03±0.30ab	24.41±0.31b
Artificial Diet 1	61.15±1.05a	49.24±1.03a	8.05±0.42c	6.15±0.29c	39.02±1.67a
Artificial Diet 2	49.42±0.57ab	39.67±0.93b	9.45±0.35a	7.67±0.14a	19.64±0.84ab

Means ± SE (N=15) within a column and followed by the same letter are not significantly different at (*P>0.05*; LSD test); ** mean of 50 females (N-=50).

TABLE III

Viability (%) of eggs, larval and pupal stages of C. punctiferalis *on artificial and natural diets*

Diets	Mean (%) survival		
	Eggs	Larvae	Pupae
Natural diet	79.20±3.85ab (N=35)	84.70±0.50b (N=45)	82.35±1.80a (N=30)
Artificial diet 1	92.45±1.30a (N=35)	95.46±1.85a (N=45)	91.50±2.55a (N=30)
Artificial diet 2	63.75±2.85b (N=35)	72.9±1.87ab (N=45)	69.84±1.30b (N=30)

Means ± SE within a column and followed by the same letter are not significantly different at ($P>0.05$; LSD test).

The pupal weight was higher on the artificial diet-1 compared to all the diets (61.02 mg per female, 49.24 mg per male). Therefore, artificial diet-1 proved superior over natural and artificial diet-2. Accordingly, the artificial diet formulated by Ambanna (2014) for *C. punctiferalis* rearing resulted that minimum pupal weight (0.37 mg) on plain semi-synthetic diet was significantly lower than natural and castor diet. Li *et al.* (2015) reported that mean pupal weights of 73.6 mg for males and 77.3 mg for females and a fecundity rate of 97.9 eggs / female.

Survival rates of eggs, larvae and pupae also were significantly affected by diets. Li *et al.* (2014) observed that the survival and reproduction of *C. punctiferalis*were impacted by the choice of the host plant material incorporated in meridic diets. The viability of the egg stage from females reared on artificial diet-1 (92.45%) was higher than artificial diet-2 (63.75%) and natural diet (79.20%) (Table III). Percentage survival of larvae from egg to pupation and pupae from larvae to adult emergence on Artificial diet-1 proved superior over natural and artificial diet-2 and the data showed statistical significant difference among the three diets offered aid lebitum to *C. punctiferalis* (Table III). Possibly, the high viability values obtained on artificial diet-1 are related to the fact that artificial diet have more quantity and equilibrium of nutrients required for the insect development. Cohen (2004) suggested that relative amounts of components of artificial insect diet impact performance and fitness of insects. Li *et al.* (2015) found that highest concentration of chestnut meal contained diets resulted in enhanced survival rate, shortened developmental duration, increased pupal weight, and increased number of eggs produced by females.

TABLE IV

Fertility life table of C. punctiferalis *from the parameters of moths reared on artificial diets (1&2) and natural diet. Mean generation time (T), net reproductive rate (R_0) and intrinsic rate of increase (r_m)*

Diets	Parameters		
	T^1(d)	R_o^1	r_m^1
Natural diet	38.75 8b	145.2b	0.067
Artificial diet 1	30.90 c	210.8c	0.071
Artificial diet 2	44.65 a	95.45a	0.034

[1] parameters (N=4)followed by the same letter do not differ by the Jaccknife test

Generation time (T) for artificial diet-1 was shorter than that with natural diet and artificial diet-2 (Table IV). These biological parameters produced a net reproductive rate (*Ro*) (The rate of population increased in each generations) of 145.2, 210.8 and 95.45 on the natural, artificial diet-1and artificial diet-2, respectively. The r_m value is an indicator of fitness, with a higher value indicating a higher level of fitness. The r_m value for *C. punctiferlis* larvae fed on the artificial diet-1 (0. 071) was higher than natural diet (0.067) and artificial diet-2 (0.034). Li *et al.* (2015) reported that the r_m value of 0.074 for the cohort fed on artificial diet indicating a higher level of fitness than the cohort fed on fresh corn and other diets.

In summary, the development of a successive rearing method using an artificial diet for *C. punctiferalis* under laboratory or other artificial conditions was successful. We believe that castor capsule powder and less aomunt of casein were key components for the succes of this diet in enhancing *C. punctiferalis* performance. This artificial diet also has the following favorable characters. The diet is economical for rearing of *C. punctiferalis*; most materials used are common foodstuff and chemicals that are easily accessible; It making procedure is simple and easy to follow. The cost of Rs. 70-80/- for 1,000g of diet is enough to rear 150 larvae to pupae. This diet possesses favourable properties for the successive rearing. Larvae feeding on it exhibited superior performance in multiple life-history traits during four continuous generations of rearing. The diet is efficient to use. The whole process is convenient, time-efficient, and requires less labour than the conventional rearing.

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BIOLOGY OF CASTOR SHOOT AND CAPSULE BORER, *CONOGETHES PUNCTIFERALIS* GUENEE ON CASTOR (*RICINUS COMMUNIS* L.)

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Abstract: The shoot and capsule borer, *Conogethes punctiferalis* Guenee (Lepidoptera: Crambidae) is a serious pest of castor, commonly called as peach yellow moth and incurring huge yield losses. Hence, the present study was conducted on biology of shoot and capsule borer under laboratory conditions. Our biological study revealed that gravid female lays pale yellowish, oval flat eggs singly on capsules, inflorescence (raceme). The incubation, larval, prepupal, and pupal periods were 2.51±0.85, 13.25±3.35, 2.75±0.80 and 9.50±0.70 days respectively. The adult longevity of male and female was 7.50 – 9.00 and 8.00±0.70 days, respectively. C. *punctiferalis* took about 30.37 – 35.30 days with on an average 30.65±3.70 days to complete life cycle from oviposition to adult emergence on castor.

Keywords: Adult longevity, Biology, Castor, Shoot and capsule borer.

Introduction

Castor (*Ricinus communis* L.) is one of the important non-edible oilseed crop, belonging to belonging to *Euphorbiaceae* family. India is the leading country in castor production and dominates the castor oil exports market to the industrialized nations in the world. Castor seed has 48% oil but only 4% can be extracted, while the cake retains the rests (Ganesh *et al.,* 2013). The major constraint for lower productivity due to the damage caused by the insect pests *viz*., castor semilooper, shoot and capsule borer, leaf miner, red hairy caterpillar, castor butterfly etc.. Among them, shoot and capsule borer, *Conogethes punctiferalis* Guenee (Lepidoptera: Crambidae) is the most destructive pest, commonly called as yellow peach moth and is distributed in tropical Asia, East Asia, Australia and various parts of the world. The caterpillars of this pest are typically polyphagous attacking more than 120 wild and cultivated plants *viz*., durian, pomegranate, peach, chestnut, citrus, papaya, eggplant and maize (Sekiguchi, 1974; Ganesh *et al.,* 2013), and is incurring about 16-72% yield loss in Maharastra (Bilapate and Talati, 1977). In view of importance of shoot and capsule borer on

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castor crop, the present study was undertaken on biology of *C. punctiferalis*. Our study will provide information, which may prove to be valuable in developing strategies for the management of this pest.

Materials and methods

Study on the biology of *C. punctiferalis* was carried out in the laboratory of the Division of Entomology and Nematology, ICAR-Indian Institute of Horticultural Research, Hessaraghatta Lake PO, Bengaluru ($12^0$58'N and $77^0$35'E; 890 m MSL) during August to December, 2015-16 at ambient temperatures and RH. Larvae/pupae contained in infested shoots and capsules were collected from Gandhi Krishi Vignan Kendra (GKVK), Bengaluru and farmers field, and kept in plastic container (90 cm x 30 cm x 45 cm) for insect rearing. Fresh capsules were provided in every four days interval. After pupation, pupae were transferred to specimen tubes for adult emergence used for further studies. 15 pairs (15 female and 15 male) of freshly emerged adults were released into the ventilated glass cages (60 x 60 x 60 cm) containing castor inflorescence (raceme) with flowers and young capsules were placed in 500 ml conical flask with water to mimic natural ambience and fed with 10 per cent honey solution soaked in cotton swabs/wads for mating, oviposition and to record the longevity of adults. The plant parts containing the freshly laid eggs were transferred to petridishes for hatching. The emerged larvae were provided with fresh capsules and rearing was continued till adult emergence. Observations were recorded on duration of egg, larvae of each instar, pre-pupa, pupa and adult stages.

Result and discussion

Gravid female moth laid whitish yellow, oval flat eggs singly on capsules, inflorescence (raceme). The incubation period varied from 2.51±0.85 days (Table 1; Figure 1) which are close arguments with the observations made by Patel and Gangrade (1971); Stanley *et al.* (2009) and Ganesh *et al.* (2013), they observed the egg period of 2-4 days.

C. punctiferslis caterpillar moulted four times and thus, there were five larval instars. The newly hatched larvae actively moved on the surface of capsules for 9-14 minutes to find suitable feeding site. The first instar larva was minute, light pinkish brown colour with pale black spots on all over the body but they were less visible, and dark coloured head and prothorax. The average duration of first instar larval was 2.85 ±0.70 days (Table 1). The second and third instar larvae were light brown with eye spot and dark mandibles. The average duration of second and third instars larvae was 2.50 ±0.55 and 2.25±0.75 days, respectively (Table 1).

The last two instars of the castor shoot and capsule borer were similar to earlier instars in colour and morphological characters except the size. The larvae of these instars were light brown with dark brown head, with very dark spots on the body. The larvae hang on with a fine silken thread when disturbed. The average durations of fourth and fifth instar larvae were 2.70±0.85 and 2.95±0.50 days, respectively (Table 1).

In the laboratory total larval period ranged from13.50- 16.60 days with an average of 13.25±3.35 days (Table 1; Figure 1). While total larval period reported to be 12.73 days, when it reared on castor (Bilapate and Talati, 1978), 17, 11.25-12.50 and 12.78 days as reported by Gour and Sriarmulu (1992); Yatihish (2012) and Ganesh *et al.* (2013), respectively, however, the slight variation in relation to other authors may reveal the effect of host plant and locality of the insect. Duration of larval stage occupied 23.82 days on cocoa and 32 days on apple was reported by Alagar *et al.* (2013) and Kadoi and Kaneda (1990), respectively.

The growth and development of different stages of larva varied with varying temperature and relative humidity. The results of biology of *C. punctiferalis* revealed that each larval instar lasted for 2.5-3 days and the total larval period extended upto 13-16 days with varying 29.50^{0}C and 85-90 per cent RH. The larvae after hatching feed on immature capsules and shoots, affected shoots show bore holes covered with frass and capsules are webbed together with dark excreta and other matter. These results were in line with, Thyagaraj (2003) revealed that the larval period varied from 12.55±2.00 to 19.59±5.50 days and the per cent survival varied from 49.6±0.18 to 92.8±1.39, 28.0±1.0^{0}C and 80.0±5.0 percent RH were most favorable for the development of larval stages. The duration of the larval stage varied from 20-23 days in August-September (at 21-35ºC) to 22-26 days in October - January (at 14-28ºC) and larvae were present in the field until February (Patel and Gangrade, 1971).

The colour of the pre-pupa was light greenish with dark spots over the body. Pre-pupal period lasted from 2.50 to 3.20 days (Table 1). The freshly formed pupa was brownish yellow with dark compound eyes. Later the pupa turned light brown. Pupation takes place inside the infested capsule. Pupal period lasted for 9.00 to 10.50 days (Table 1; Fig.1). These results were in accordance with Ganesh *et al.* (2013), who reported the pupal duration of 7-9 days. Yathish (2012) recorded that 2.55- 2.88 days and 9.50 -12.00 days of pre-pupal and pupal period.

The adults were medium sized moth, brownish yellow body with a straw yellow wings having number of dark spots (Figure 1). Generally, female moths were bigger in size, having

bulged abdomen and male moths were smaller in size and tufts of hairs are absent in the abdomen tip. Adult longevity of female and male ranged from 8.75 – 10.00 and 7.50 -9.00 days, respectively (Table 1). The longevity of female and male moth was 6.5 and 5.7 days (Sekiguchi, 1974; Alagar *et al.,* 2013). Ganesh *et al.* (2013) observed that longevity of male and female moths 8.00-9.45 days and 9.00 – 10.65 days. This variation may be due to changed weather conditions.

In the present investigation on bioecology of the insect pest is highly variable depending upon the weather parameters, host plant and habitat strategy of the pest under different cultivated ecosystems is difficult. Hence, location-specific studies on *C. punctiferalis* are necessary for evolving rational pest management strategies.

Table 1. Duration of different life stages of *Conogethes punctiferalis* on castor

Insect Stages	**Duration (Days)**	
	Range	**Mean±SD**
Egg	3-4	2.51±0.85
I instar	2.5 – 3.5	2.85±0.70
II instar	2.00 – 3.00	2.50±0.55
III instar	2.00 – 3.50	2.25±0.75
IV instar	2.50 – 3.00	2.70±0.85
V instar	2.50 – 3.50	2.95±0.50
Total larval period	13.50 – 16.60	13.25±3.35
Pre-pupa	2.50 – 3.20	2.75±0.80
Pupa	9.00 – 10.50	9.50±0.70
Adult longevity of male	7.50 – 9.00	8.00±0.70
Adult longevity of female	8.75 – 10.00	9.50±0.25
Total developmental period (Egg-Adult)	30.37 – 35.30	30.65±3.70

Figure 1. Life stages of *Conogethes punctiferalis*

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OVIPOSITIONAL BEHAVIOR OF CASTOR SHOOT AND FRUIT BORER, CONOGETHES PUNCTIFERALIS GUENEE (*Lepidoptera : Crambidae*) ON CASTOR PLANT

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ABSTRACT

Conogethes punctiferalis Guenee (*Lepidoptera : Crambidae*) is a polyphagous destructive pest of castor and is commonly called as castor shoot and fruit borer and yellow peach moth. It is distributed in Tropical Asia, East Asia and Australia and various parts of the world. The larvae of *C. punctiferalis* fed on seeds in the capsules, the excreta plugged at the entry hole on the shoot indicated larval boring and causing huge yield losses. Hence, the present investigation was conducted on ovipositional preference of castor shoot and fruit borer at Division of Entomology and Nematology, ICAR-Indian Institute of Horticultural Research, Hessaraghatta, Bengaluru, during 2015-16 under laboratory conditions. Our observations on ovipositional preference on different substrate and plant parts revealed that the gravid female moths laid maximum number of eggs on the cotton plug (41.97%) and castor twings (41-48 eggs/ female). The Oviposition pattern of female moths found that the highest number of eggs (82) were found on cotton plug in total life span of female moth, the highest fecundity was found between days 3 to 5, that is 18, 25, and 20 on third, fourth and fifth days, respectively. The same pattern was observed on the all oviposition substrates. Information of hierarchies of host plant oviposition preference by castor shoot and fruit borer females will be useful in developing strategies for the management of this pest.

Key words : *Castor, Conogethes punctiferalis, Cotton plug, Ovipositional preference, Twings*

The castor shoot and fruit borer, *Conogethes punctiferalis* Guenee (*Lepidoptera: Crambidae*) is one of the most destructive pest of castor and is widely distributed in tropical and eastern Asia, Australia andvarious parts of the world. Larvae of this species are polyphagous pest attacking more than 120 both wild and cultivated crop plants viz., peach, plum, pomegranate, guava, durian, papaya, chestnut, citrus, eggplant, maize etc., (Sekiguchi, 1974; Waterhouse 1993; Du *et al.,* 2016). It is commonly known as yellow peach moth which may cause damage more than 50 per cent (Bilapate and Talati, 1977). Management of this insect has been largely based on insecticides, but the most insecticides are associated environmental problem has necessitated searching for some alternative method for its control with minimum negative environmental impacts (Kranthi *et al.,* 2002; Indrakant *et al.,* 2015).

Development of effective alternative strategies requires a thorough understanding about the biological relationships of pest with host plant. A very important aspect of such relationship is that of ovipositional preferences but the knowledge on this with respect to *C. punctiferalis* is limited. The objectives of our study to evaluate ovipositional preference of castor shoot and fruit borer, *C. punctiferalis* grown in India. Our study will provide information, which may prove to be valuable in developing strategies for the management of this pest.

MATERIALS AND METHODS

Experiment was conducted at Division of Entomology and Nematology, ICAR-Indian Institute of Horticultural Research, Bengaluru, Karnataka, India during 2015-16 under laboratory conditions to determine the most suitable substrate for oviposition by gravid female moths of the borer. Castor field collected larvae were used for initiating the culture of *C. punctiferalis* on castor at temperature of 28-32ºC and 85-90%, relative humidity with 14:10 light/dark cycle. The larvae were reared on fresh capsules in plastic containers (90cm × 30cm × 45cm). Fresh capsules were provided at every three day intervals. After pupation, they were transferred to specimen tubes for adult emergence which were used for further studies. Five pairs (5 males and 5 females) of freshly emerged adults were released into the insect rearing cage (35 × 45 × 20 cm) for mating and oviposition. The cage was provided castor inflorescence along with four substrates viz., cotton plug (used for fixing the bouguet to the bottle of water), castor capsules, cotton dipped in water and cotton wad dipped in 10% honey solution were used for the study.

Plant parts *viz.*, capsule/inflorescence, leaves (fully opened), peduncle, petiole, main stem, secondary branches, tertiary branches and twigs (unopened leaves) were also placed in experimental cage along with red light was provided in the cage with 15W (decoration) red lamp fixed from the top or hang between two cages. Red light is known to be essential as stimuli for mating and laying fertile eggs. Red light was provided from 9 PM to 6 AM in the laboratory (Ambanna, 2014). The ovipositional substrates as described above were provided in the cage and observations were recorded on number of eggs laid

Table-1 : Oviposition preference on selected substrates by gravid females

Days	Percentage of the eggs laid on different substrates			
	Cotton plug *	Castor capsules	Water swab	Honey swab
1	0	0	0	0
2	50.5	44.5	0	0
3	59	51.7	9.2	2.5
4	56.5	36.5	8.5	3.9
5	47.3	29.2	12	5
6	38.5	22.6	24.5	5.6
Mean	41.97	30.75	9.03	2.83

*Which was used to fix the bouquet of castor capsules to the bottle of water, n=5 pairs of moths.

Table-2 : Oviposition preference on different plant parts by gravid females.

Plant parts	Average number of eggs
Capsule/Inflorescence	9-11
Leaves (Fully opened)	1-2
Peduncle	0
Petiole	1
Main stem	0
Secondary branches	0
Tertiary branches	0
Twigs (Unopened leaves)	41-48

n=5 pairs of moths

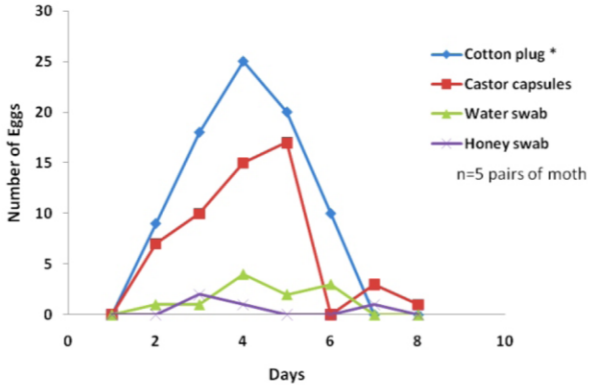

Figure-1 : Oviposition pattern by gravid Conogethes punctiferalis females.

on different substrates and plant parts. All statistical analysis was based on either actual number of eggs laid by the gravid females or as mean percentage of eggs laid.

RESULTS AND DISCUSSION

Oviposition preference on different substrates and plant parts : Study on different substrates for oviposition by female moths revealed that highest mean percent oviposition (41.97%) were observed on the cotton plug, followed by young castor capsules, (30.75%) water swab, (9.03%) and the least mean per cent oviposition was recorded on the honey swab (2.83%) dipped in 10 percent honey solution. This experiment clearly showed that the gravid female moths laid maximum number of eggs on the cotton plug (Table-1). Ganesh *et al.* (2013) found that the gravid female moths were deposited their eggs singly on capsules and cotton wads. Stanley *et al.* (2009) reported that the female moths laid their eggs singly or in groups in between the warts or just below the style on the ovary of the flowers and on the developing capsule to up the half mature stage. In the absence of red light even though moths could lay eggs they were sterile so the red light was found essential for *Conogethes* moths to lay fertile eggs.

Investigation on ovipositional preference on different plant parts by gravid females resulted that maximum number of eggs (41-48 / Female) was recorded on castor twigs and then the inflorescence/capsules (9-11 eggs/female) were preferred by the moths for Oviposition (Table 2). This information may help in mass rearing techniques for the borer. Patel and Gangrade (1971) reported that, the eggs were laid in groups of 1 - 6 on the inflorescences and capsules by *C. punctiferalis* moths and the egg stage lasted from four days at 30ºC to 11 days at 20ºC. Devasahayam *et al.* (2010) reported that adult moth laid eggs on the tender unopened leaf of ginger.

Oviposition pattern of gravid female moths : Information on the peak oviposition activity of the moths was elucidated. Observations recorded on the ovi-position pattern by gravid female moths under lab conditions, on four substrate viz., cotton plug, castor capsules, water swab and honey swab suggested that egg laying commenced on the second day after adult emergence, and peak ovi-position was between 3-5 days and started declining from the sixth day onwards and it was nil on day 9. The highest number of eggs (93) were found on cotton plug in total life span of female moth, the highest fecundity was found between days 3 to 5, that is 18, 25, and 20 on third, fourth and fifth days, respectively. The same pattern was observed on the all oviposition substrates. On castor capsules 10, 15 and 17 eggs on third, fourth, and fifth days, respectively were found. Out of 53 eggs, 49 were found on between 2-5 days. On water swab, out of 11

eggs, 10 were found between 3- 6 days and on honey swab out of 4 eggs, 3 were found between 3-4 days. On cotton plug and castor capsules, maximum number of eggs was recorded between day 3 to day 5 (Fig.1). The development of the pyralid, *C. punctiferalis* was investigated on apple fruits by Kadoi and Kaneda (1990) in Japan under laboratory conditions and reported that the number of eggs laid on caged fruits averaged 25 at 26^{0}C and 70 per cent relative humidity. Ganesha *et al.* (2013) studies revealed that the egg period of *C. punctiferalis* ranged from 2–4 days on castor. Fecundity ranged from 80-110 eggs per female with a mean of 22.33±0.8, 54.50±2.6, 53.75±2.4 eggs on spineless spike, compact spiny and spiny loose type of castor, respectively (Doddabasappa *et al.,* 2014).

The nature of the host plant cues for eliciting behavioural responses from insects could be chemical, tactile, visual, or some combinations. Since *C. punctiferalis* is nocturnal moth the role of visual cues in selection of host plant for oviposition may be minimum, and as such role of chemical and tactile cues are most important in host plant discrimination and oviposition. This is also evolutionary important that ovipositional preferences hierarchy of females should correspond with the nutritive value of the potential hosts for sustenance of next progeny. Wild and cultivated host plants of *Conogethes* sp. serve as important reservoirs for populations for subsequent infestation of other crops. Successful management of these populations, and especially avoidance of severe outbreaks, will require a more complete understanding of armyworm ecology in the diverse ecological system within which crops are grown.

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