TRI-TROPHIC INTERACTIONS OF HOST PLANTS, APHID, *Aphis craccivora* Koch. AND COCCINELLID BEETLE, *Cheilomenes sexmaculata* (Fabricius)

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B.Sc. (Ag.)

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(ENTOMOLOGY)

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BY

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B.Sc. (Ag.)

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2015

DECLARATION

I, **SNEHASISH ROUTRAY**, hereby declare that the thesis entitled "**TRI-TROPHIC INTERACTIONS OF HOST PLANTS, APHID, *Aphis craccivora* Koch. AND COCCINELLID BEETLE, *Cheilomenes sexmaculata* (Fabricius)**" submitted to the **Acharya N.G. Ranga Agricultural University** for the award of degree of **Master of Science in Agriculture** is the result of original research work done by me. I also declare that no material contained in the thesis has been published earlier in any manner.

Place : **(SNEHASISH ROUTRAY)**

Date : **I.D. No. TAM/2013-17**

CERTIFICATE

Mr. **SNEHASISH ROUTRAY** has satisfactorily prosecuted the course of research and that thesis entitled **"TRI-TROPHIC INTERACTIONS OF HOST PLANTS, APHID, *Aphis craccivora* Koch. AND COCCINELLID BEETLE, *Cheilomenes sexmaculata* (Fabricius)"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that neither the thesis nor its part thereof has been previously submitted by him for a degree of any university.

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CERTIFICATE

This is to certify that the thesis entitled **“TRI-TROPHIC INTERACTIONS OF HOST PLANTS, APHID, *Aphis craccivora* Koch. AND COCCINELLID BEETLE, *Cheilomenes sexmaculata* (Fabricius)”** submitted in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE IN AGRICULTURE** to the Acharya N.G. Ranga Agricultural University, Hyderabad, is a record of the bonafide research work carried out by **Mr. SNEHASISH ROUTRAY** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance and help received during the course of the investigations have been duly acknowledged by the author of the thesis.

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Snehasish.....✍

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LIST OF SYMBOLS AND ABBREVIATIONS

H	:	Hour
%	:	Per cent
@	:	At the rate of
°C	:	Degree centigrade
cm	:	Centimetre
cm^2		Square centimetre
mm	:	Millimetre
et al.,	:	And others
Fig.	:	Figure
i.e.	:	That is
viz.,	:	Namely
etc.	:	and so on; and other people/ things
g	:	Gram
mg	:	Milligram
mg/g	:	Milligram per gram
ml	:	Milli litre
S.D.	:	Standard Deviation
S.E.	:	Standard Error
ANOVA	:	Analysis of Variance
DMRT	:	Duncan's Multiple Range Test
r	:	Correlation coefficient
R^2	:	Regression coefficient
rpm	:	revolutions per minute
>	:	More than
<	:	Less than
±	:	Plus or minus
Nm	:	Nanometer
M	:	Molarity
RH	:	Relative humidity
Fig.	:	Figure

ABATRACT

Name of the Author	:	**SNEHASISH ROUTRAY**
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The present study on “Tri-trophic interactions of host plants, aphid, *Aphis craccivora* Koch. and coccinellid beetle, *Cheilomenes sexmaculata* (Fabricius)” was carried out in Department of Entomology, S.V. Agricultural College, Tirupati. Six host plants *viz.*, cowpea (CO-702), groundnut (K-6), cotton (Narasimha), sunflower (DRSH-1), greengram (LGG-410) and blackgram (LBG-791) were grown in pots, in polyhouse conditions. Excised leaves from these plants of equal physiological maturity were used for studying the biology of *A. craccivora* at 28±2^{o}C temp and 75-80% RH.

Among all the tested host plants, the preference ranks of (most preferred to least preferred) of host plants for *A. craccivora* are cowpea> groundnut> greengram> blackgram> sunflower> cotton.

Longest oviposition period, fecundity and adult longevity of aphid reared on cowpea (188.40±28.87 h; 52.00±10.92; 231.60±40.41 h), put cowpea as the most preferred host plant for growth and multiplication of *A. craccivora* followed by groundnut (85.50±11.89 h; 21.12±2.64; 100.80±54.61 h), greenram (96.00±62.51 h; 12.62±8.38; 99.60±77.36 h), blackgram (75.00±63.74 h; 9.87±8.67; 86.40±73.27 h). Highest aphid nymhal mortality was noticed, when they were reared on cotton and sunflower (100%) and lowest nymphal mortality was noticed in cowpea (0%). Highest nymphal mortality, production of very few parthenogenetically inactive adults ceased the post nymphal periods in sunflower and cotton and put cotton and sunflower as the least preferred host for growth and multiplication of *A. craccivora*.

Highest body size (body length and body width) of aphids was obtained, when they were reared on cowpea followed by greengram, blackgram and groundnut.

Trichome densities of different host plants were negatively correlated with adult longevity, fecundity and total life span and were significantly positively

correlated with percentage nymphal mortality of *A. craccivora*. Comparatively higher proteins, free amino acids, total soluble sugars and less trichome density, phenols and reducing sugar content in cowpea leaves were preferred by aphids for growth and development. Whereas, higher trichome density, phenol content and reducing sugars in leaves of cotton and sunflower caused highest nymphal mortality of *A. craccivora*.

When aphids reared on different host plants were fed to lady beetle *C. sexmaculata*, total larval duration was longest on groundnut reared aphids followed by blackgram> greengram> sunflower> cowpea> cotton. Adult male beetle longevity was longest on cowpea (14.00±0.70 days), whereas longevity of female beetle was longest on groundnut (17.75±1.06 days). During the entire life span, *C. sexmaculata* consumed highest no. of aphids when aphids were reared on groundnut followed by blackgram, greengram, cowpea, sunflower and cotton.

Because of low nutritional status of groundnut plants, aphids reared on these plants would also be low in their nutritional status and hence the both grubs and adults of *C. sexmaculata* consumed more number of aphids and also took longer period of time to complete their life cycle.

Because of high nutritional status of cowpea, nymphs and adult aphids reared on cowpea were bigger and because of high nutritional status of aphids reared on cowpea both grubs and adults of *C. sexmaculata* consumed fewer number of aphids and took less time to complete their life cycle. The biochemical constituents (phenols) present in cotton and sunflower which contributed to aphid nymphal mortality, also affected the biology and feeding potentiality of lady bird beetle (third trophic level) with highest larval mortality.

Chapter – I

Introduction

Chapter I

INTRODUCTION

Arthropod herbivores such as insects and mites are considered as pests in many agricultural systems. They damage by feeding directly or acting as vectors of diseases of plants that are meant for human use or consumption. Use of synthetic pesticides might be one of the simplest ways of managing these. However, some of these arthropod pests are well equipped to counteract some of these synthetic pesticides by development of new resistant individuals. One of an alternative method of pest control is to exploit all natural enemies found on these arthropod herbivores, and to use against them (biological control). For any successful biological control programme, we need to understand the relationship between the plant, the herbivores (insect pests) (direct response) and their natural enemies (indirect response), as well as the factors that can influence these interactions (Reddy and Guerrero, 2013).

There are strong links between direct defense (host plant resistance) and indirect defense (biological control), and these links can be mediated by a variety of physical and chemical plant factors. Indirect plant defense, where the plant benefits from the natural enemies of herbivores, essentially involves tri-trophic interactions (DeMoraes *et al.*, 2013).

Tri-trophic interaction involves interactions between three trophic levels, *viz.*, the plant, the pest (herbivore) and the natural enemy (carnivore). Plant attributes can affect herbivores, natural enemies of herbivores and their interaction. Such effects are mediated by primary plant attributes (*i.e.*, nutritional quality and physical structure) and by defense-related products (*i.e.*, secondary chemicals and plant volatiles). Nutrient availability to plants can affect the composition of insect communities and this can subsequently influence top-down forces *i.e.* carnivores on herbivore populations with consequences for plant population biology (Dicke, 2008). The study of tri-trophic interactions is important in order to understand natural species interactions and to manipulate these interactions in pest control strategies (Agrawal, 2000).

Studies of tri-trophic interactions aim to identify these interactions, understand their mechanistic basis and document their consequences. Ultimately, manipulating these interactions may result in better pest control and the reduced use of pesticides (Chadwick and Goode, 1999).

Aphid, *Aphis craccivora* Koch., a highly polyphagous pest, is known by several names such as cowpea aphid, black legume aphid, groundnut, aphid etc. It is reported to feed on about 80 plant families but prefers feeding on plants belonging to family Fabaceae. Cowpea, groundnut, cotton, sunflower, greengram and blackgram are economically important crops that are attacked by *A.craccivora*. This insect not only causes direct damage by sucking sap from plants, but also involved in transmission of viral diseases such as rosette virus in groundnut, poty virus in sunflower etc., (Singh *et al.,* 2005). This insect also causes significant damage to green gram and blackgram foliage and pods along with other related legumes (Swaminathan *et al.,* 2012).

Cheilomenes sexmaculata (Fabricius) (Family: coccinellidae) is a generalist predator having a wide host range. Members of this family are popularly known as ladybird beetles, ladybirds, lady bugs or lady beetles. These beetles are cosmopolitan in distribution, with about 420 genera and 6000 species worldwide. Most of the members of this family are beneficial as predators of aphids, mealybugs, scales, psyllids, whiteflies, and other Homopteran eggs and early instar of order Lepidoptera, Coleoptera, Thysanoptera, Diptera, and Acarina.

The physical, morphological, physiological and biochemical characteristics of plants affects biology and feeding potential of insect herbivores (second trophic level) feeding on them, which in turn influence the biology, feeding potential, searching ability etc., of the natural enemies (third trophic level) feeding on these insect herbivores.

A resistant cultivar reduces the vigour of insect pest, prolonging its life-cycle hence making it more vulnerable to natural enemies (Dhaliwal and Dilwari, 1993). Physical factors of plants also affect the efficacy of natural enemies. The searching behaviour of the parasitoid *Trioxys indicus* Subba rao & Shrama of *A. craccivora* is affected by the foliar pubescence of the aphid host plants (Bhatt and Singh, 1989).

Though ample work has been done on interaction between host plants and insect herbivores, information on effect of host plants on insect herbivores in particularly aphids and it's in turn effects on morphometrics, biology and feeding potentiality of coccinellid beetle is scanty.

So, an attempt was made here to study the tri-trophic interaction among host plants, insect herbivores and natural enemies with the following objectives.

1. To study the effect of host plants (cowpea, groundnut, cotton, sunflower, greengram and blackgram), on the biology of aphid *A. craccivora* Koch.
2. To study the biochemical components (protein, total soluble sugars (TSS), phenols, free amino acids and reducing sugars) of six hosts and correlate them to aphid performance.
3. To study the biology of the coccinellid beetle feeding on aphids reared on six different host plants.
4. To study the feeding potentiality of the predator *Cheilomenes sexmaculata* (Fab.) on aphids reared on six different host plants.

Chapter ~ II

Review of Literature

Chapter II

REVIEW OF LITERATURE

Reviews related to the objectives of present study *i.e.,* "Tri-trophic interactions of host plants, aphid, *Aphis craccivora* Koch. and coccinellid beetle, *Cheilomenes sexmaculata* (Fabricius)" are written in this chapter.

2.1 APHIDS AS CROP PEST

Aphids are small, soft bodied insects belonging to the Family Aphididae of Order Hemiptera, and Suborder Homoptera. Around 4702 species of aphids are known worldwide and 653 species are known from India (Rajendran, 2002).

They are a truly interesting group of herbivorous insects and can affect plants directly or indirectly by feeding on the plant's sap. They are associated with many host plants in the Leguminosae and also in many other plant families attacking about 50 crops in 19 different plant families (Blackman & Eastop, 2007). In India nearly 1250 plant species belonging to 700 genera under 175 plant families are fed by 653 species of aphids accommodated under 208 genera.

They are also called as 'plant lice', sucking cell sap from their host plant and hence are serious agricultural pests. Aphids not only causes damage by sucking sap from plants, but also cause damage involving in transmission of viral diseases such as rosette virus and peanut stripe virus in groundnut, poty virus in sunflower (Singh *et al.,* 2005), cowpea mosaic virus (CMV) etc. About 300 species of aphids are vectors of 300 different viruses (Eastop & Lambers, 1976).

Aphid, *A. craccivora* Koch. a highly polyphagous pest, is known by several names such as cowpea aphid, black legume aphid, groundnut aphid. It is reported to feed on about 80 plant families but prefers feeding on plants belonging to family Fabaceae. Cowpea, groundnut, cotton and sunflower are economically important crops that are attacked by *A. craccivora.*

In cowpea, it causes about 20-40 per cent loss in Asia and about 35 per cent loss in Africa (Singh and Allen, 1980). *A. craccivora* Koch. may cause up to

100 per cent yield loss in different varieties of country bean (*Lablab purpureus*), barbate (*Vigna sesquipedalis*), black gram (*Vigna mungo*), mung bean (*Vigna radiata*) and cowpea (*Vigna unguiculata*) in different places (Ganguli and Roychaudhury, 1984). About 16 per cent of yield losses were recorded in groundnut in India due to a complex of insect pests, the predominant one being *A. craccivora* (Jagtap *et al.*, 1984).

2.2 BIOLOGY OF *A. CRACCIVORA* ON DIFFERENT HOST PLANTS

2.2.1 Biology of *A. craccivora* on cowpea

Among all the host plants, cowpea was the most suitable for *A. craccivora* (Srikanth and Lakkundi, 1988). They studied the host preference of *A. craccivora* in lablab, cowpea, green gram, black gram, pea and soybean where pea and soybean were completely avoided by this insect. They also reported that the average nymphal period, adult longevity and duration of total life cycles (in days) of *A. craccivora* was 4.84 days, 10.42 days and 15.26 days respectively when reared on cowpea. Mean fecundity of single female was 47.5 with daily average nymphs laid was 6.09 on the same host.

A. craccivora had four nymphal instars on cowpea (*Vigna unguiculata* L.) in the laboratory, the average nymphal period were 5.6, 5.1, 5.15 and 4.86 days, respectively, in May-June, August-September, October-November and March-April. The corresponding durations of the total life cycle were 11.07, 11.15, 10.79 and 10.42 days (Patel and Srivastava, 1989).

Kaakeh and Dutcher (1993) studied the development time, fecundity, nymphal mortality, generation time, intrinsic and finite rates of increase and population doubling time for *A. craccivora*, reared on seedlings of *Sesbania exaltata, Indigofera hirsuta, Vicia villosa, Trifolium incarnatum*, rye and cowpea. Development, pre-reproductive and generation times of *A. craccivora* were shortest on cowpea, followed by *S. exaltata* and *I. hirsuta*. However, mean total fecundity, fecundity rate, and intrinsic and finite rates of increase were higher on cowpea and *I. hirsuta* than on the other species.

Hafiz (2006) studied the effects of seven cowpea cultivars (Pinkeye, Chinese-Reds, Black-Crowder, Balady, Tvu-21, Six-Weeks and IT 82 D889) on the development period of *A. craccivora*. He reported that the duration period of nymphal stages ranged from 7.22 days on Six-Weeks cultivar to 8.19 days on B-Crowder cultivar. Aphid individuals fed on Six-Weeks cultivar developed significantly faster than those on any other cultivars, whereas, it had longer development time on B-Crowder cultivar. The total life span on the seven cultivars (Pinkeye, Chinese-Reds, Black-Crowder, Balady, Tvu-21, Six-Weeks and IT 82 D889) were 7.96 days, 7.36 days, 8.05 days, 7.22 days, 8.19 days, 7.59 days and 7.66 days respectively.

Angayarkanni and Nadarajan (2008) studied the biology and seasonal activity of *A. craccivora* in cowpea ecosystem and revealed that the aphid remained active throughout the year. They also reported that the aphid's nymphal period, pre-reproductive period, reproductive period, post-reproductive period and adult longevity was 7.6 days, 4.53 days, 6.57 days, 2.03 days and 13.39 days respectively. The fecundity was reported as 53.02 per female with an nymph production of 8.07 per day per aphid.

In laboratorial olfactometer experiments the study of effect of host odour on population of cowpea aphid *A. craccivora* Koch., it was found that among the four different host plants tested, more number of alatae responded to the cues emanating from cowpea leaves (1.6) followed by that from glyricidia (1.4), *Dolichos* (0.4) and groundnut (0.4). Apterous morphs also responded more to cowpea (1.6) followed by dolichos (0.6), groundnut (0.4) and glyricidia (0.2) (Jaba *et al.*, 2010). They concluded that cowpea was the most preferred host plant to *A. craccivora* followed by glyricidia.

2.2.2 Biology of *A. craccivora* on groundnut

Reddy *et al.* (1983) reported that on four cultivars of groundnut *viz.*, JM-59, Jawahar-1, Sulemath and Jyoti, *A.craccivora* had longevity of 2.50, 2.40, 2.20 and 2.10 days respectively with mean fecundity of 6.20, 3.80, 4.40 and 3.60 respectively.

Srikanth and Lakkundi (1988) reported that the *A.craccivora* had a nymphal period, adult longevity and duration of total life cycle of 6.67 days, 5.25 days and 11.92 days respectively when grown on groundnut. On the same host mean fecundity of the aphid was 16.8 with daily average fecundity of 4.15.

Prasad *et al*. (2008) reported the incidence of *A. craccivora* in groundnut is high in *rabi* followed by *kharif* and summer season.

2.2.3 Biology of *A. craccivora* on cotton

Eight aphid species known to colonize on cotton in the United States and throughout the world namely *Aphis gossypii* Glover, the cotton or melon aphid; *A. craccivora* Koch, the cowpea aphid; *Aphis fabae* Scopoli, the bean aphid; *Aphis maidiradicis* Forbes, the corn root aphid; *Macrosiphum euphorbiae* (Thomas), the potato aphid; *Myzus persicae* (Sulzer), the green peach aphid; *Rhopalosiphum rufiabdominalis* (Sasaki), the rice root aphid; and *Smynthurodes betae* Westwood (Stoetzel *et al.,* 1996).

A. gossypii usually have shortest development time at 27.5-28°C. At these temperatures, the aphids took 5.0 and 5.18 days to reach maturity. The optimal temperature for fecundity as measured in nymphs/adult/day was different: 25°C versus 20°C, which resulted in 2.85 versus 2.69 nymphs/adult/day respectively (Ebert and Cartwright, 1997).

Mogeni and Rezwani (1998) reported four different species of aphids *viz*., *A. gossypii*, *A. craccivora*, *Acyrthosiphon gossypii*, and *Myzus persicae* in cotton field in Gorgan region, Iran. Among them, *A. gossypii* was the dominant species with an abundance of nearly 97 per cent in the area. *A. gossypii* had a peak of activity from early August to mid-September at a temperature and relative humidity in the range 24-28 ^{o}C and 65-75 per cent RH, respectively. It had a life cycle 6-7 days and longevity 20-26 days (24±1^{o}C and 75±5 per cent RH) respectively. A rearing study also revealed that this species had the ability to reproduce up to 68 individuals in wingless and 32-44 in alate under laboratory conditions and the numbers of larvae (one of apterous viviparous) in varied conditions (in mid-June) were between 28 and 56.

Sapkota (2004) reported that *A. gossypii* had total nymphal durations of 5.25 days, 4.38 days and 4.53 days at temperatures of 25°C, 30°C and 35°C respectively. At those temperatures pre-reproductive period was 0.65 days, 0.83 days, 0.78 days, lifetime fecundity was 44.75, 53.08, 13.94 with adult longevity of 29.65 days, 28.21 days and 14.22 days respectively.

Razmjou *et al.* (2006) studied the development, survivorship, and life table parameters of the *A. gossypii* at 27.5±1°C, 65±10 per cent RH, and a photoperiod of 14:10 (L:D) h of artificial light on five commonly growing cotton cultivars: Varamin, 'Sealand' (relatively resistant cultivar), 'Bakhtegan', 'Sahel' (both relatively susceptible cultivars), and 'Siokra'. The developmental times of immature stages ranged from 4.6 d on Bakhtegan and Varamin to 6.3 d on Sealand, whereas the immature stage survival was 97.5 to 65 per cent on Sahel and Siokra, respectively. On average, there were 28.7, 28.3, 23.5, 20.1, and 16.8 nymphs produced per female on Sahel, Bakhtegan, Varamin, Sealand, and Siokra, respectively.

Vennila *et al.* (2007) reported that *A. gossypii* live in colonies and the alate as well as apterous females multiply partheno genetically and viviparously. In a day a female may give birth to 8-22 nymphs. Nymphal period lasts for 7-9 days and the adults live for 12-20 days. In all the pest has 12-14 generations per year.

Out of the three commonly found aphid species on cotton *viz.*, the cotton aphid (*A. gossypii*), green peach aphid (*Myzus persicae*) and cowpea aphid (*A. craccivora*), cowpea aphid is sometimes found on seedling cotton in late spring after legume crops die off, but rarely establishes effectively in cotton plants (Wilson *et al.*, 2008).

Masia (2010) reported that *A. gossypii, A. spiraecola, Myzus persicae* and *Toxoptera aurantii* are the principal aphid species attacking on cotton. Whereas, *A. craccivora, A. fabae, Aulacorthum solani, Brachycaudus helichrysi* and *Macrosiphum euphorbiae* are the secondary aphid species attacking the same.

2.2.4 Biology of *A. craccivora* on sunflower

Field studies at Bapatla, Andhra Pradesh, on the pest complex of sunflower indicated total of 22 arthropod species on sunflower. The most important species were *Atractomorpha crenulata* (F.), *A. craccivora* Koch, *A. gossypii* Glov., *Spodoptera litura* (F.), *Pericallia ricini* (F.), *Plusia signata* (F.) and *Diachrysia orichalcea* (F.) (Ayyanna *et al.*, 1978).

Among viral diseases, sunflower mosaic caused by potyvirus and this virus is transmitted by *A. craccivora* Koch. (Singh *et al.*, 2005).

Plum curl aphids (*Brachycaudus helichrysi*) and black sugarbeet aphids (*A. fabae*) were the most important aphids infesting sunflower causing the considerable damages (Thalji, 2006).

2.2.5 Biology of *A. craccivora* on greengram

The adults and nymphs of *A. craccivora* suck the cell sap from underside of the tender leaves, growing tips, flower stalks and pods. It causes 25.6 and 29.9 per cent damage at vegetative and reproductive stages, respectively on mung bean during kharif season (Sahoo and Pattanaik, 1994). In severe infestation, the pods become malformed causing 20 - 40 per cent yield loss in Asia (Singh and Allen, 1980).

Srikanth and Lakkundi (1988) reported that the aphid have nymphal period, adult longevity and duration of total life cycle about 6.43 days, 6.04 days and 12.47 days respectively when grown on greengram. On the same host mean fecundity of the aphid was 21.2 with daily average fecundity of 4.26.

Patel and Srivastava (1989) reported that the total life period of *A. craccivora* averaged 10.57 days when reared on greengram with mean fecundity of 17.57.

Li *et al.* (1994) reported that *A. craccivora* was closely correlated with the mung bean growth period. The aphid migrated into the fields when the plants had produced two to three true leaves, showed the greatest population increase at the start of flowering, peak population density and damage at full flowering, and a rapid population decrease at the full podding stage.

Comparative biology of *A. craccivora* was studied on 11 green gram varieties by Purnima Das Dutta (1999) under laboratory conditions. Of the four nymphal instars of the aphid, only third instar duration was significantly affected by the varieties. The first, third and fourth instar durations varied from one to two days each on the green gram varieties. The second instar occupied 1.5 to 2 days. Comparatively longer period of nymphal development (6.75 days) was recorded on the variety PMB-14; whereas, AAU-34 recorded the shortest developmental period (5.00 days).

Out of 23 genotypes of greengram screened against *A. craccivora,* four designated as resistant, five moderately resistant, five intermediate, five susceptible and four highly susceptible. Their findings reveal that the aphids population ranged from 64.0–234.0 per 2.5 cm terminals shoot length and foliar damage index ranged from 0.6–3.5 per plant (Hafeez *et al.,* 2007).

2.2.6 Biology of *A. craccivora* on blackgram

Srikanth and Lakkundi (1988) reported that the average nymphal period, adult longevity and duration of total life cycles (in days) of *A. craccivora* was 5.19 days, 5.15 days and 10.34 days respectively when reared on blackgram. Mean fecundity of single female was 19.5 with daily average nymphs laid about 4.62 on the same host.

Patel and Srivastava (1989) reported that the total life period of *A. craccivora* averaged 9.61 days when reared on blackgram with a mean fecundity of 17.43.

2.2.7 Morphometrics of *A. craccivora*

Morphotaxonomy is regarded as a reliable and powerful tool among applied entomologists for discrimination of aphid taxa (Poulios *et al*., 2007).

The genus *Aphis* is one of the most difficult genera of aphids to identify because of morphological conservation and this problem is complicated by the fact that several species may live on a single host plant. They are recognisably associated with their host plants (Blackman, 1975).

Reddy *et al.* (1983) reported that the body size of adult *A. craccivora* was highest (1.948 mm^2) on bean, followed by Arhar (var. T-21) (1.532 mm^2), Arhar (var. Bahar) (1.49 mm^2), Arhar (var. G-3) (1.43 mm^2), Arhar (var.Jyoti) (1.024 mm^2) and Lentil (var. JL-1) (0.873 mm^2) when reared on respective host plants. They also reported that the antennal length was longest (1.281 mm) when reared on Bean and was shortest (0.969 mm) when reared on Arhar (var. G-3).

Usmani and Rafi (2009) reported that apterus *A. craccivora* had body length of 1.94 mm, width 1.28 mm, antennae 1.48 mm, siphunculus 0.42 mm and cauda 0.26 mm. Whereas alate form had body length of 2.22 mm, width 1.03 mm, antennae 1.42 mm, siphunculus 0.28 mm and cauda 0.19 mm.

Mehrparvar *et al.* (2012) reported significant differences in twelve morphological characters among *A. craccivora* collected from different host plants (*Astragalus* sp., *Atriplex leucoclada* Boiss., *Chenopodium album* L., *Robinia pseudoacacia* L., *Tripleurospermum disciforme* (C. A. Mey) Schultz Bip. and *Zygophyllum eurypterum* Boiss & Buhse). Out of all four morphological characters (siphunculus length, ultimate rostral segment length, basal diameter of siphunculus and processus terminalis length) from which two (siphunculus length and ultimate rostral segment length) showed the highest contribution to the separation of host-associated populations and 87.6 per cent of individuals were reclassified correctly into their original populations. The result of morphometric analyses performed here revealed the existence of three morphologically differentiated groups within *A. craccivora* associated with different host plants which provide evidence for the presence of host related forms.

2.3 HOST PLANT CHARACTERS AFFECTING PERFORMANCE OF *A. CRACCIVORA*

2.3.1 Bio-physical characters

Plant bio-physical characters such as pubescence, trichomes, leaf thickness etc. affect the performance of sap sucking insects including aphids. Leaf pubescence (Krips *et al.*, 1999) and lack of cuticular waxblooms (Eigenbrode and Kabalo, 1999) can impair the development of herbivores.

Johnson (1953) reported that hooked trichomes on the French bean (*P. vulgaris*) may have profoundly detrimental effects on populations of *A. craccivora*, nymphal mortality ranging from 13 to 73 per cent as a function of hair density.

Hairiness/ trichomes act an important insect non-preference trait against the sucking insect pests of cotton. The degree of hairyness or trichome density on the leaves of *Gossypium* species and cultivars is related to varying degrees of resistance/susceptibility to sucking pests (Meagher *et al*., 1997).

Pubescence nature has the opposite effect on aphid, *A. gossypii* feeding on muskmelon (Kennedy *et al.*, 1978).

Ahmed *et al*. (1987) concluded that greater hairy density and gossypol glands contributed towards jassid resistance in cotton.

Leaf domatia are small hair-tufts or pockets on the abaxial surface of leaves that have been found in nearly 300 plant families and 2000 species (Brouwer, 1990). When artificial domatia were added to cotton plants, several species of predators increased in abundance, populations of three species of herbivores decreased, and cotton yield was enhanced compared to controls (Agrawal *et al.*, 2000).

Joseph and Peter (2007) reported that the non-preference mechanism of aphid resistance was evidenced under free choice conditions of migration and settling of *A. craccivora* on some cowpea lines. The tender most shoot tips of the resistant cowpea lines were densely pubescent with mixed types of trichomes. Bell (1980) also reported more pubescence on aphid resistant cowpea cultivars.

2.3.2 Bio-chemical characters

Principal carbon and nitrogen sourses utilized by most aphids are sugars (especially sucrose) and amino acids (Dadd, 1985). Niraz *et al.* (1985) reported a direct relationship between soluble proteins and aphid infestation in wheat crop.

Out of these two major classes of nutrients, amino acids are considered particularly important in the ecological context, because dietary nitrogen concentration may be a major determinant of aphid population increase (Brodbeck and Strong, 1987).

Srivastava and Auclair (1974) reported that the presence of amino acids increased the acceptability of diets of the pea aphid, *Acyrthosiphon pisum* to a great extent, as uptake on such diets was two to five times more than that on amino acid free diets. Uptake was lowest on diets lacking amino acids, and highest on those containing 3.5 and 2.5 per cent amino acids.

Leszczynski *et al.* (1989) reported that total phenol content in winter wheat was negatively correlated (r = -0.946) with the intrinsic growth rate (r_m) of grain aphid *Sitobion avenae* (F.) conferring resistance to it.

Chen *et al.* (1997) reported that two isogenic aphid (*A. gossypii*) resistant melon (*Cucumis melo* L.) lines were containing a low total amount of free amino acids (less than 10 mM).

Narang *et al.* (1997) reported that susceptibility of barley to corn leaf aphid *Rhopalosiphum maidis* (Fitch.) was favoured by high amount of soluble proteins and total soluble sugar content. However, higher concentration of phenols was associated with resistant nature of the plant. The correlation coefficient between total free amino acids in leaves and corn leaf aphid population was positive but non-significant. The amount of total free amino acids varied from a minimum of 4.09 mg/g in the genotype AR-48 to a maximum of 17.34 mg/g in AR-19.

Mohamed and Siman (2001) conducted the several field screening trials using different varieties of broad bean for their resistance reaction against *A. craccivora* and reported that high susceptibility or heavy infestation of the broad bean varieties was possibly due to higher nitrogen and protein content in plant leaves and stem.

Karley *et al.* (2002) reported that 'pre-tuber-filling stage' of potato plants *Solanum tuberosum* was susceptible to aphids *Myzus persicae* and *Macrosiphum euphorbiae* having high free amino acid level whereas, 'tuber-filling' stage harboured low aphids having low free amino acids.

The effects of three cotton cultivars with low (ZMZ13), medium (HZ401), and high (M9101) gossypol contents on the development, reproduction, and survival of *A. gossypii* Glover were investigated. Developmental duration and immature survivorship did not vary between aphids on the three cultivars, whereas *A. gossypii* feeding on M9101 (high gossypol cultivar) displayed significantly shorter adult longevity and lower fecundity than aphids fed on ZMS13 and HZ401 (Du *et al.,* 2004).

Balakrishnan (2006) reported total phenol, gossypol and tannin contents in different plant parts (leaves, squares and bolls) of different cotton varieties/ hybrids had shown significant negative relationship with the incidence of leafhoppers, aphids, whiteflies and thrips.

Joseph and Peter (2007) reported that the protein content was lowest in the *A. craccivora* resistant cowpea line Vs438 (19.75%) and the highest in that of susceptible line Pusa Komal (24.35%). Higher levels of total sugars (5.96 mg/g) was recorded in susceptible cowpea lines (Pusa Komal) when compared to resistant lines (4.35 mg/g in Vs 438). They reported that the resistant lines had more reducing sugars (1.12-3.80 mg/g) but less non reducing and total sugars.

Khattab (2007) reported the role of phenol peroxidases in defense mechanism of aphid (*Brevicoryne brassicae* L.) infested cabbage leaves.

Macfoy and Dabrowski (2009) studied the resistance nature of some cowpea lines to *A. craccivora* and reported that the basis of resistance was probably antixenosis and antibiosis. Chemical analysis showed correlations of total phenols and total flavonoids with resistance. However, total sugars and total amino acids did not exactly show such correlations.

Mariana *et al.* (2010) reported high level of amino acids in susceptible lines of soybean to aphid (*Aphis glycines*) whereas low level of the same was detected in aphid resistant soybean lines.

Rohini *et al.* (2011) reported that maximum phenol content (0.084%) was found in DHY-286 sel and Gcot-16 (0.073%) (leafhopper resistant variety of cotton). The minimum phenol content was reported in variety CPD-431 (0.016%) and LK-861 (0.02%) which are found susceptible to leafhoppers.

Masood (2014) reported the association of low sucrose content and high phenol content in resistance nature of canola to aphids (*Myzus persicae*). Same author also reported that low sucrose content and high phenol content confer resistance in cotton to aphids *Myzus persicae*, *Macrosiphum euphorbiae* and *Aulacorthum solani*. Average no. of aphids were positively correlated with protein content (r = 0.890) and negatively correlated with glucose content (r = -0.760) (reducing sugar).

2.4 BIOLOGY OF COCCINELLID BEETLE *C. SEXMACULATA* (FAB.) (=*MENOCHILUS SEXMACULATUS*)

Coccinellids are considered to be of great economic importance and they have been successfully employed in the biological control of many injurious insect pests and are easily available in agricultural ecosystem (Irshad, 2001).

The zigzag beetle, *Menochilus sexmaculatus* (Fab.), commonly known as lady bird beetle is a predaceous coccinellid with wide distribution in South Western Asia, Indonesia, Philippines, South Africa, Pakistan and India. The predatory beetle is an efficient feeder and preys on a wide range of soft bodied insects including aphids, plant hoppers, thrips, jassids, scale insects, mealy bugs and white fly infesting large number of cultivated crops (Rahman *et al.*, 1993; Solangi *et al*., 2007).

Suja and Beevi (2007) studied the efficacy of the potential predators of the pea aphid *A. craccivora* infesting cowpea in laboratory. Among the major predators, the coccinellids, *Coccinella transversalis*, *Harmonia octomaculata* and *Menochilus sexmaculatus*, were found to be efficient ones.

Sorokhaibam and Dutta (2011) studied the spatial distribution of *C. sexmaculata* (Fabricius) on bean Aphid, *A. craccivora* Koch in Green Gram ecosystem in Assam and reported the positive binomial (regular) distribution of *C. sexmaculata* in the field at both larval and adult stages in both *kharif* and *Rabi*.

2.4.1 Egg stage

Lefroy and Howlett (1909) working on the biology of *C. sexmaculata* reported that the egg period varied from 4.0 to 5.0 days. According to Subramanyam (1923), the eggs were yellow; cigar shaped and laid in batches of 10 to 15 on the lower surface of leaves. The eggs hatched within 2.0 to 3.0 days. Bagal and Trehan (1945) reported that eggs of *C. sexmaculata* were yellow and cylindrical with tapered/ rounded ends laid singly or in clusters on the underside of leaves which hatched in 2.0 to 3.0 days.

C. sexmaculata eggs, which were yellow, cylindrical with tapered and, rounded ends, were laid singly or in clusters on the undersides of leaves and hatch in 2.0 to 3.0 days (Selhime, 1955). According to Trehan and Malhotra (1959) the incubation period varied from 2.0 to 5.0 days. Seshadri (1970) reported that the incubation period of egg of *C. sexmaculata* was 1.75 days.

Patel and Vyas (1989) reported that the duration of egg period was 1.49 days. Patel (1989) reported the incubation period of egg was 2.5 days when reared on bean aphid, *A. craccivora*. Verma *et al.* (1993) reported that egg stage of *C. sexmaculata* lasted for an average period of 2.0±0.2 days and the hatching percentage was 93.40, when reared on *A. gossypii* Glover under laboratory condition.

Zala (1995) reported the incubation period of egg of *C. sexmaculata* was 3.0 days. Veeravel and Baskaran (1996) reported that when *C. sexmaculata* was fed on *A. gossypii* at different temperatures such as, 18°C, 24°C, 30°C and 36°C, the duration of the egg stages were 2.45,1.71,1.48 and 1.43 days, respectively.

Mean egg period of *C. sexmaculata* feeding on *A. craccivora* was 1.68±0.16 days (Rai *et al.,* 2003). Suja and Beevi (2007) reported that the duration of egg stage of *C. sexmaculata* when fed on *A. craccivora* was 2.10 days. Freshly laid eggs were cigar shaped, yellow in colour with smooth chorion and without any reticulations and turned blackish with advancement of age and became completely black before hatching. Tank and Korat (2007) reported that the eggs were usually laid in clusters of five to 12 and each cluster consist four to 27 eggs. Incubation period varied from one to three days with an average of 1.40±0.66 days.

According to Solangi *et al.* (2007) egg incubation period of *C. sexmaculata* was 7.5, 7.1 and 7.2 days when reared on aphids, *R. maidis, A. gossypii and T. trifolii* respectively.

The effect of three constant temperatures *i.e.*, 22±1˚C, 28±1˚C and 34±1˚C on the egg incubation of *Menochilus sexmaculatus* Fab. was 4.22±0.12, 3.64±0.11 and 2.12±0.11 days (Ali *et al.,* 2013).

2.4.2 Grub stage

Subramanyam (1923) observed the larvae of *C. sexmaculata* moulted thrice and thus there were four instars and freshly hatched larvae were dark grey in color with shining dark head capsule and legs.

Selhime (1955) reported that the first stage larva was black, but after the first moult, it acquires yellow markings along the back. The larvae moult three times and during their entire larval stage they are very active and feed voraciously and in 6.0 or 7.0 days the larvae pupate, usually on the undersides of leaves. Four larval instars were also observed by Gupta (1966) and duration of four instars varied from 2.0 to 3.5, 2.0 to 4.0, 2.0 to 4.0 and 2.5 to 4.0 days, respectively.

Veeravel and Baskaran (1966) reported that when *C. sexmaculata* feed on *A. gossypii* at different temperatures like 18°C, 24°C, 30°C and 36°C, the duration of the first larval instar was 2.63, 1.76, 1.58 and 1.50 days, respectively; the second larval instar was 2.60, 1.90, 1.55 and 1.40 days, respectively; the third larval instar was 2.86, 1.96, 1.50 and 1.60 days respectively and the duration of the fourth instar was 2.60, 1.86, 1.51 and 1.40 days, respectively.

Das and Rava (1968) reported the grub period was of 8.0 days. Similarly, four grub instars were observed by Seshadri (1970) and the duration of each instar of *C. sexmaculata* was on an average of 1.52, 1.26, 1.26, and 1.0 days, respectively.

Zala (1995) observed that the first, second, third and fourth larval instars of *C. sexmaculata* lasted for 2.58, 3.16, 3.25 and 2.87 days, respectively when reared on *Lipaphis erysimi* under laboratory conditions.

Babu (2001) reported that the larval and pupal duration of *C. sexmaculata* when fed on *A. gossypii* adults and nymphs were 17.0±0.28 and 15.4±0.45 days.

Rai *et al.* (2003) reported that the developmental period of I, II, III and IV instars of *C. sexmaculata* feeding on *A. craccivora* was 1.6±0.15, 1.2±0.08, 1.48±0.11 and 4.24±0.15 days, respectively. Suja and Beevi (2007) reported that the duration of four instars of *C. sexmaculata* were 1.20, 2.80, 3.60 and 3.80 days, respectively.

Tank and Korat (2007) reported that the larvae of *C. sexmaculata* moulted thrice and thus there were four instars. Freshly hatched larvae were dark grey in colour with shining dark head capsule and legs. The average duration of the first instar was 1.80±0.50 days. Second instar larvae were glistening black in colour with yellow coloured head capsule and black legs. The average duration of the second instar was 1.72±0.46 days. Freshly moulted third instar larvae were dull black in colour with yellow head capsule. The colour pattern was more intensified with additional development of white spots on mid-dorsal line of other segments except prothorax. The average duration of the third instar was 1.88±0.53 days. Fourth instar was deep black in colour, when freshly moulted but changed to black in colour before pupation and it developed additional rectangular dark grey spots in a continue series mid-dorsally on abdominal segments. The average duration of the fourth instar was 1.96±0.73 days.

The grubs of *Menochilus sexmaculatus* passed through four instars to reach pupal stage. Feeding of different host aphids did not significantly influence the duration of various life stages of *M. sexmaculatus* where duration of first, second, third and fourth instars ranged between 6.5-7.0, 4.5-5.5, 3.9-6.5 and 6.5-8.5 days, respectively (Solangi *et al.,* 2007).

The first, second, third and fourth instar larval period of *C. sexmaculata* lasted for 2.67±0.33 days (ranged two to three days), 2.00±0.58 days (ranged one to three days), 2.67±0.33 days (ranged two to three days) and 4.00±0.58 days (ranged three to five days) respectively (Kumar *et al.*, 2013).

The effect of three constant temperatures *i.e.*, 22±1˚C, 28±1˚C and 34±1˚C on the total larval duration of *C. sexmaculata* was 9.48±0.09, 7.89±0.07 and 5.65±0.07 days (Ali *et al.,* 2013).

2.4.3 Pupal stage

According to Subramanyam (1923), the pupal period of *C. sexmaculata* lasted for 3.0 to 4.0 days and almost similar period was also reported by Modawal (1941), Puttarudraiah and Chennabasavanna (1954) and Das and Rava (1968). Selhime (1955) stated that the pupa was yellow with a thin black margin on the wing pads and two rows of black marks down the abdominal segment and the pupal duration lasted for two or three days.

Veeravel and Baskaran (1966) reported that when *C. sexmaculata* fed on *A. gossypii* at different temperatures like 18°C, 24°C, 30°C and 36°C, the duration of the pupal stage lasted for 5.00, 3.90, 2.76 and 2.45 days respectively.

Seshadri (1970) reported that the pupal duration lasted for 2.08 days. Patel (1989) observed the pupal period of *C. sexmaculata* as 3.86 days.

Zala (1995) reported that the average pre-pupal and pupal periods of *C. sexmaculata* was 16.08 h and 3.16 days respectively.

The average pupal period of *C. sexmaculata* was 2.68±0.14 days (Rai *et al.,* 2003). Solangi *et al.* (2007) reported that duration of pupal period *Menochilus sexmaculatus* ranged between 3.1 and 5.5 days.

Suja and Beevi (2007) reported that the duration of pre pupal and pupal periods were 1.80 and 3.40 days respectively. When larvae was about to pupate, it undergoes a very short pre-pupal period, turns wood brown in colour and assumes curved shape and attach itself posteriorly to the leaf surface. Freshly formed pupae were shining yellow and later on turned to pale orange yellow. They were symmetric orange black spots on each segment. The average pre-pupal and pupal periods were 1.72±0.45 days and 3.36±0.70 days, respectively (Tank and Korat, 2007).

The pre-pupal period of *C. sexmaculata* was lost in 2.67±0.33 (ranged 23 days) while the pupal period was lost in 4.67± 0.33 days (ranged 4-5 days) (Kumar *et al.*, 2013).

The effect of three constant temperatures *i.e.*, 22±1˚C, 28±1˚C and 34±1˚C on the pupal duration was 4.28±0.08, 3.69±0.05 and 2.24±0.06 days (Ali *et al.*, 2013).

2.4.4 Adult stage

The whole life cycle took 17.0 to 20.0 days at 77°F temperature, while 23.0 to 30.0 days at room temperature (Modawal, 1941). Ranaweera (1947) observed that the entire life cycle of *C. sexmaculata* was completed within 15.0 to 19.0 days and almost similar period was also observed by Rehman (1941). The *C. sexmaculata* lady beetles completed their development from egg to adult in 11.0 to 12.0 days at a mean temperature of 82.5°F (Selhime, 1955).

According to Gupta (1966) the pre-oviposition, oviposition and post-oviposition periods were observed to be on an average of 2.0, 10.85 and 0.56 days, respectively.

Azim and Ahmed (1966) studied the life history of *C. sexmaculata* and stated that at a mean temperature of 28.7°C, the total life cycle was completed on an average of 18.0 days. Gupta (1966) studied that longevity of male and female which was on an average of 15.0 and 21.0 days respectively. Kawauchi (1979) reported that the duration of development of *C. sexmaculata* raised with rise in temperature up to 30°C.

According to Patel and Vyas (1989), the pre-oviposition, oviposition and post-oviposition periods of *M. sexmaculata* were on an average of 2.43, 16.83 and 2.60 days, respectively. The oviposition potential of mated female ranged from 242 to 1173 eggs with an average of 616.7 eggs.

Verma *et al.* (1993) reported that the pre-oviposition, oviposition and post-oviposition periods of *Menochilus sexmaculatus* were on an average of 3.8±1.0, 43.3±5.0 and 4.1±1.7 days respectively.

According to Zala (1995) longevity of male and female beetles was 16.2 and 20.21 days when they were given food whereas without food the longevity was 3.07 and 3.69 days, respectively. Veeravel and Baskaran (1996) reported that when *C. sexmaculata* feed on *A. gossypii* at different temperatures like 18°C, 24°C, 30°C and 36°C, the total life period was 18.14, 13.19, 10.38 and 9.8 days respectively. Eswaramoorthy *et al.* (1998) conducted a study on the longevity of *C. sexmaculata* and stated that the mean duration of development was 11.3±2.4 days when reared on *Melanaphis indosacchari* (Zehntner) and the adults survived for 12.7±3.1 days when fed with aphids.

Nandakumar (1999) observed the total duration of *Menochilus sexmaculatus* from egg to adult was 15.35 days.

Babu (2001) reported that the longevity of *C. sexmaculata*, when fed with adult and nymphs of *A. gossypii*, were 32.6±0.35 and 36.4±0.45 days, respectively. The pre-oviposition, oviposition, fecundity per day and longevity periods of *M. sexmaculatus* when fed with *Myzus persicae* was 4.7±0.46, 28.5±1.33, 30.5±1.59 and 16.6±6.4 (Khan and Khan, 2002).

Suja and Beevi (2007) reported that the total life cycle of *C. sexmaculata* was 18.70 days and the longevity of the adult was 31.5 days. Newly emerged adults were soft bodied, yellowish in colour without any markings which turned shining yellow or warm buff with black spots which developed gradually. The adults were small, oval, convex dorsally and flat ventrally. Abdomen and eyes were light yellow in colour whereas elytra and pronotum were marked with zigzag markings.

Solangi *et al.* (2007) reported that duration of pre-oviposition, oviposition and post-oviposition periods of *Menochilus sexmaculatus* were 3.1-3.7, 23.4-27.7 and 3.5-4.5 days respectively. Adult life span ranged as 30.0-35.0 days.

The entire life span of both male and female of *C. sexmaculata* were 29.72±2.20 and 34.15±2.54 days respectively. The mean pre-oviposition, oviposition and post-oviposition periods of *C. sexmaculata* when fed with *A. gossypii* were 2.61 ±0.76, 14.38±2.36 and 3.23±0.72 days respectively. Male and female beetles survived from 10.0 to 21.0 and 15.0 to 26.0 days with a mean survival period 16.09±2.54 and 20.23±2.80 days respectively. Longevity of male without food was 2.0 to 4.0 (2.5±0.68) days while female it was 3.0 to 5.0 (3.35±0.58) days (Tank and Korat, 2007).

In a life table study of *C. sexmaculata* by Ali and Rizvi (2009) at varying temperatures of 20±1°C, 24±1°C and 28±°C 1 it was found that it took shortest developmental period (41 days) at 28±1°C and longest developmental period (49 days) at 20±1°C.

The adult female longevity at three constant temperatures *i.e.*, 22±1˚C, 28±1˚C and 34±1˚C was 56.83±0.45, 42.47±0.42 and 36.07±0.32 days (Ali *et al.*, 2013).

Kumar *et al.* (2013) reported that *C. sexmaculata* completed their life cycle in 18-27 days. *C. sexmaculata* laid eggs ranged 150-210 eggs during her life period. Male and female beetles survived for 29-33 and 33-38 days with a mean survival period of 30.67±0.88 and 35.33±1.45 days, respectively.

2.5 FEEDING POTENTIALITY OF *C. SEXMACULATA* (FAB.) ON APHIDS

According to Modawal (1941), a single grub of *C. sexmaculata* can feed on 310 aphids (*A. craccivora*) per week under laboratory conditions. Bagal and Trehan (1945) reported that the maximum number of aphids consumed by an individual adult was on an average of 60.84 per day under laboratory conditions. An individual larva of *M. sexmaculatus* consumed a maximum of 303 aphids in their entire development period.

Azim and Ahmed (1966) observed that *M. sexmaculatus* attacked all stages of the aphid. The average number of aphids consumed daily per grub was generally increased with age from 17.2 for grub of one day old to 50.0 for grub of eight days old. The number of aphids consumed daily by the adult varied from 12.0 to 50.0 with an average of 32.4. According to Gupta (1966), there were four grub instars and each grub instar have a capacity to feed up on 21.6, 26.1, 29.9 and 32.1 adults of maize aphid (*R. maidis*), respectively, whereas adult can fed up to 37.6 aphids per day.

Feeding potential of *C. sexmaculata* were undertaken by Devi (1967) in Kerala and found that the average feeding potential of first, second and third instar larvae were 7.11, 38.44 and 70.78 aphids respectively under laboratory conditions. Adult was found to consume 27.22 aphids per day. Ray (1967) reported that the number of aphids consumed by the grub of *M. sexmaculatus* was 165.0 to 203.0 during the entire life span.

Seshadri (1970) reported the average number of aphids (*A. craccivora*) consumed by different instars of *C. sexmaculata* as 20.22, 37.45, 40.21 and 47.21 aphids, respectively. Sharma (1975) reported that *M. sexmaculatus* feeds on different species of aphids. The adult consumed on an average of 20.6, 21.0, 31.3, 29.0, 17.6 and 12.0 aphids' species of *Brevicoryne brassicae*, *Acyrthosiphon pisum*, *L. erysimi*, *A. craccivora*, *A. gossypii* and *R. maidis* respectively. Haque and Islam (1978) reported that coccinellid predator; *M. sexmaculatus* can feed 21.1 to 41.7 aphids (*A. craccivora*) per day.

Verma *et al.* (1983) reported that the feeding potential of *C. sexmaculata* on *A. craccivora* was found to be 28.7, 35.40, 32.20 and 30.70 aphids, respectively for first, second, third and fourth instar grubs.

Patel and Vyas (1989) reported that a single *M. sexmaculatus* consumed on an average of 474.0 aphids during 6.0 days of larval development and 16.0-49.0 days of adult life. Patel (1989) reported predatory capacity of first, second, third and fourth instars to be 7.60, 16.28, 23.39 and 26.5 aphids per day respectively. Whereas the predatory capacity of *M. sexmaculatus* during its total grub period varied from 47.0 to 121.0 aphids (*A. craccivora*) with an average of 107.5 aphids. Aphid consumption varied from 378.0 to 684.0 with an average of 546.64 aphids during the adult life span. He also further reported that every day adult was able to prey on an average of 72.5 bean aphids (*A. craccivora*) and 48.7 maize aphids (*R. maidis*).

However, *C. sexmaculata* consumed 143-189 individuals of *Aphis nerri* (Bose and Ray, 1967) and 350 - 400 nymphs of *A. craccivora* (Patel and Vyas, 1989).

Lokhande and Mohan (1990) and Rani (1995) reported that a single grub of *M. sexmaculatus* consumed 73.52 and 84.00 aphids respectively. Das (1991) reported that one larva of *M. sexmaculatus* consumed 270.0 to 367.0 *A. craccivora* with an average of 312.90±6.91 prior to pupation.

Kumar (1992) reported that larvae of *C. sexmaculata* consumed 383.0 *L. erysimi* during their development and further observed that the feeding capacity increased in every successive instar. During the development of the first, second, third and fourth instars, a mean of 16.0, 19.1, 33.8 and 70.9 of *A. craccivora*, respectively, were consumed by a *M. sexmaculatus* grub.

Verma et al. (1993) reported that grub of *C. sexmaculata* consumed 598.5±45.3 *A. gossypii* during its life stage, whereas the aphid consumption per female was 277.1±41.5 aphids as against 206.2±21.7 aphids by a male.

Brar and Shenhmar (1995) reported that the four instars of *C. sexmaculata* consumed 28.2, 55.4, 105.6 and 115.1 number of aphids and a total of 304.3 aphids were consumed. According to Zala (1995), the feeding capacity of *M. sexmaculatus*, during larval and adult period, was on average of 193.0 and 507.3 mustard aphids (*L. erysimi*). He also reported that adults of *M. sexmaculatus* consumed on an average of 19.74, 29.53, 24.30, 23.93, 18.60 and 15.60 aphids of *B. brassicae*, *L. erysimi*, *A. gossypii*, *A. craccivora*, *R. maidis* and *Uroleucon carthimi* Linn, per day, respectively.

Jayaramaiah *et al*. (1996) reported that *C. sexmaculata* consumed on an average of 31.20 aphids per day under Bangalore conditions. The feeding potential of *C. sexmaculata* grub was 220.2±17.4 aphids in case of *Melanaphis indosacchari* and 179.6±40.5 aphids in the case of *Melanaphis sacchari* Zehnter. *C. sexmaculata* when reared on *A. craccivora*, *L. erysimi* and *A. gossypii* showed marked differences in growth and development. The size and fecundity of predator was greater when fed on *A. craccivora* (Rao and Rao, 1997).

The adult beetles of *C. sexmaculata* prayed on an average of 992.8±256.8 *M. indosacchari* and 1403.3±99.9 *M. sacchari* respectively (Eswaramoorthy *et al.*, 1998). Nandakumar (1999) stated that the mean consumption of *A. gossypii* Glover by first, second and third instar grubs of *C. sexmaculata* were found to be 11.2, 51.45 and 121.45 aphids, respectively. The mean consumption of *A. gossypii* adults by an adult coccinellid during the entire life span was 827.90 and it ranged from 386 to 1494.

Babu (2001) reported that the four different larval instars *C. sexmaculata* consumed 18.2±0.33, 26.0±0.84, 32.6±0.60 and 37.6±nymphs and 14.6±0.35, 18.4±0.59, 26.0±0.74 and 36.0±0.74 adults of *A. gossypii*. He also reported that male adult beetle consumed 36.5±0.53 nymphs and 33.2±0.66 adults of *A. gossypii* and female consumed 56.6±0.79 nymphs and 44.0±1.26 adults of *A.*

gossypii on daily basis. Das and Premsagar (2001) observed that per day consumption of *A. craccivora* by *C. septempunctata* to be 26.97. Khan and Khan (2002) reported that the average consumption of *M. persicae* by the five developmental stages of *M. sexmaculatus* was 7.0, 35.0, 42.0, 105.0 and 240.0 per day, respectively and acquired significantly higher survival and faster development when feeding on live aphids.

Mani *et al.* (2005) studied the predatory efficiency of the beetle *C. sexmaculata*. They reported that 11.8, 26.8, 43.4 and 141.5 number of alfalfa aphids were consumed by the first, second, third and fourth grub instars under laboratory condition. Suja and Beevi (2007) reported that *M. sexmaculatus* consumed 10.7, 35.9 and 81.00 cowpea aphids by the second, third and fourth instars and a total consumption of 127.60 aphids by the predator. Singh *et al*. (2009) reported that *M. sexmaculatus* consumed 62.00±0.78 to 211.40±2.68 aphids under different predator density which ranged from 1 to 16. Similarly, the *C. sexmaculata* consumed 41.20±0.33 to 377.00±3.35 aphids under different prey density which ranged from 45 to 720 aphids.

Mean daily prey consumption by *Menochilus sexamaculatus* during the first, second, third and fourth instar and the adult stage ranged between 6.20-12.00, 20.00-27.00, 30.5-55.00, 43.27-45.27 and 72.00-82.5 aphids respectively. Mean total number of prey consumed during entire adult life was 80.08 *R. maidis*, 69.95 *A. gossypii* and 68.96 *T.trifolii* (Solangi *et al.,* 2007).

Prabhakar and Roy (2010) reported that when fed on *A. craccivora, C. sexmaculata* could consume about 48.0±1.20, 33.2±1.25 nymphs (by male and female respectively) and 41.3±0.72, 30±2.0 on adult aphids.

Mean predatory potential of all larval instars of *M. sexmaculatus* ranged from 148 to 162 aphids, respectively when reared on *Rhopalosiphum padi*. The prey consumption of adult male and female ranged from 2294 to 2422 aphids and 2912 to 3085 aphids respectively (Ali *et al.,* 2012). The predatory potential of larval stages of *M. sexmaculatus* was about 161-184 aphids when reared on

Schizaphis graminum. The same for adult male and female were 2468 to 2501 aphids and 3175 to 3356 aphids respectively (Ali *et al.*, 2013).

Kumar *et al.* (2013) reported that the total number of aphid consumed during whole larval duration of *C. sexmaculata* varied from 70 to 95 *A. craccivora* and 63 to 85 *Lipaphys erysimi*, respectively. A male beetle consumed 510.33±9.82 *A. craccivora* (ranged 500 to 521 aphids) and 410.33±4.26 *L. erysimi* (ranged 400 to 416 aphids), with an average of 28.72 *A. craccivora* and 32.92 *L. erysimi* per day, respectively. A female beetle consumed 718.00±17.21 *A. craccivora* (ranged 710 to 725 aphids) and 555.67±27.63 *L. erysimi* (ranged 547 to 571 aphids), respectively with an average of 35.93 *A.craccivora* and 27.90 *L. erysimi* per day respectively.

Pandi *et al.* (2013) reported the consumption rate of coccinellid predator *C. sexmaculata* (Fabricius) on aphid hosts, *viz.*, *A. craccivora* Koch, *A. gossypii*, *Rhopalosiphum maidis* and *Lipaphis erysimi*. The potential hosts, beginning with the best may be arranged as *A. craccivora*, *A. gossypii*, *R. maidis*, and *L. erysimi* in descending order. The fourth instar grubs consumed significantly more aphids when compared to first, second and third instars. The per day predation rate (number of aphids) by female beetle on *A. craccivora* was 37.2±3.32, followed by *A. gossypii* (35.2±2.22), *R. maidis* (31.6±2.44), and *L. erysimi* (23±0.94). Male could feed only 35.8±2.67 of *A. craccivora*, followed by 30.8±1.98 of *A. gossypii*, 27.8±4.28 of *R. maidis*, and 20.8±1.15 of *L. erysimi*. Male and female longevity was lowest (26.8±1.71 and 34.6±1.36 days) on *L. erysimi* and longest (41.6±0.98 and 48.2±2.67 days) on *A. craccivora*. The decreasing order of development rate observed of *C. sexmaculata* was *A. craccivora* > *A. gossypii* > *R. maidis* > *L. erysimi*. The decreasing order of development rate observed of *C. sexmaculata* was *A. craccivora* > *A. gossypii* > *R. maidis* > *L. erysimi*.

In another laboratory experiment by Saleem *et al.* (2014) reported that the feeding potential of first, second, third and fourth instar larvae of *M. sexmaculatus* was 8.40±0.50, 13.60±0.81, 28.60±1.50 and 57.40±4.67 aphids

(*Macrosiphum rosae* (Linneaus), respectively. The predation efficiency of male and female adults was 802.40±2.56 and 916.60±1.69 aphids respectively.

2.6 TRI-TROPHIC INTERACTIONS

Plants interact in complex ways with herbivores and pathogens that feed on plants, and with natural enemies of herbivores and pathogens (Price *et al.*, 1980).

Herbivore attack very often induces the release of specific volatiles that guide predators and parasitoids in their search for prey or host (Turlings *et al.*, 1990).

The tri-trophic role of plant chemistry is central to several aspects of trophic phenomena including top-down versus bottom-up control of herbivores, enemy-free space and host choice, and theories of plant defense. Furthermore, tri-trophic effects of plant chemistry are important in assessing the degree of compatibility between biological control and plant resistance approaches to pest control (Ode, 2006).

Durcher *et al.* (1999) studied the tri-trophic interactions between aphids (*A. craccivora*), coccinellid beetles (*Harmonia axyridis* and *Hippodamia convergens*) and the red imported fire ant (*Solenopsis invicta*). They reported that cowpea aphid (*A. craccivora*) was not an acceptable prey for multicoloured Asian ladybeetle (*Harmonia axyridis*). Cowpea aphids were eaten by convergent ladybeetle (*Hippodamia convergens*). Multicoloured Asian lady beetle were more effective than convergent ladybeetle in preventing aggressive red imported fire ants from forcing them off the plant.

Murugan *et al.* (2000) studied the influence of host plant (*Calotropis gigantea*) on growth and reproduction of *A. nerii* and feeding and prey utilization of its predator *Menochilus sexmaculatus*. Influence of different physiological stages (young, mature and senescent) of *C. gigantea* leaves on growth and reproductive ability of *A. nerii* and feeding, prey utilization, fecundity and lipid content of its predator *M. sexmaculatus* were investigated. Increased reproductive period, total life span and reproduction of nymphs per female of *A. nerii* were observed when reared on mature leaves. This relative preference of *A. nerii* and maximum utilization of mature leaves as compared to other physiological aged leaves are mainly due to changes in the chemical composition such as protein, carbohydrate, lipid, amino acid, nitrogen and phenolic of *C. gigantea*. Further, aphids reared on mature leaves influenced its predator's (*M. sexmaculatus*) growth, prey utilization and reproductive performances. Fecundity and longevity were high, while developmental time of predator was shorter on mature leaves fed aphid. Maximum prey utilization and increased efficiency of ingested and digested food of predator was observed on mature leaves reared aphid.

Giles *et al.* (2002) studied the tri-trophic interactions among host plants (*Medicago sativa* L., cv. \`OKO8' and *Vicia faba* L., cv. \`Windsor'), aphid prey (*Acyrthosiphon pisum* Harris), and predator, *Coccinella septempunctata* L.. Compared with *A. pisum* reared on *V. faba*, *A. pisum* reared on *M. sativa* stored significantly more fatty acids which resulted in a 1.17 fold increase in available caloriesfor developing *C. septempunctata*. The increased survival, decreased developmental times, and larger size of *C. septempunctata* supplied with *A. pisum* reared on *M. sativa* clearly demonstrate host plant affects at the third trophic level. At low very limiting daily prey levels, *A. pisum* reared on *M. sativa* were more suitable prey for *C. septempunctata* survival, development, and adult size than *A. pisum* reared on *V. faba*.

In a tri-trophic interactions between transgenic potato expressing the insecticidal lectin from snowdrop (Galanthus nivalis agglutinin; GNA), an aphid pest, *Myzus persicae* (Sulz.), and a beneficial predator, the 2-spot ladybird (*Adalia bipunctata* L.), there was no significant effects on development and survival of ladybird larvae fed on aphids from these transgenic plants were observed, with larval survival in the experimental group being 90 per cent compared to 89 per cent for controls. There were also no effects on subsequent female or male longevity. Female fecundity was also investigated. Although no significant differences ($p > 0.05$) were observed in egg production between control and experimental groups, a 10%, reduction ($p < 0.01$) in egg viability (determined by % hatch) occurred in ladybirds fed aphids reared on transgenic plants (Down *et al.*, 2003).

Du *et al.* (2004) studied the effect of three Cotton Cultivars (ZMZ13, HZ401 and M9101) on development and reproduction of aphid *A. gossypii* and Its coccinellid Predator *Propylaea japonica* fed aphids from M9101 (high gossypol content) showed a significantly shorter developmental period and greater adult weight than those fed aphids from the other two cultivars (medium and low gossypol content). The decreased larval developmental duration and increased adult weight of *P. japonica* fed cotton aphids reared on the high gossypol-containing cultivar might have been caused by the high fatty acid content of the prey aphids. They further stated that high gossypol in host cotton had an antibiotic effect on *A. gossypii* and showed a positive effect on growth and development of *P. japonica* at the third trophic level.

Hopkinson (2010) studied the host acceptance behaviour of the parasitoid *Lysiphlebus testaceipes* when offered *A. craccivora* Koch and *A. gossypii* reared on cotton, hibiscus or mungbean. *L. testaceipes* accepted more *A. craccivora* than *A. gossypii* and more aphids on mungbean than on cotton. *L. testaceipes* had a preference for *A. craccivora* and mungbean compared to *A. gossypii* and cotton. The effect of developmental stage on host acceptance was studied by observing *L. testaceipes* with second, fourth and adult stages of *A. gossypii* or *A. craccivora*. *L. testaceipes* had a preference for older (fourth and adult) stages of development over a younger (second) instar. Observations of host acceptance behaviour revealed that *A. gossypii* cornicle secretion was an effective deterrent, capable of disabling *L. testaceipes* and thus preventing it from making further attempts at parasitising hosts. This effect was not observed in *A. craccivora*.

In another tri-trophic study involving two host plants, aphids (*Myzus persicae*) and predator (*Adalia bipunctata*), it was found that the aphid feeding on sweet pepper had better suitability for the predator due to better nutritive value; whereas the same aphid feeding on tabacco was least suitable for the predator due to toxicity nature (Jalali and Michaud, 2012).

Barkhordar *et al.* (2013) studied the Impact of host plant resistance on the tri-trophic interactions between wheat genotypes, aphids (*Schizaphis graminum*), and coccinellid beetle, *Coccinella septempunctata*. They reported that four wheat genotypes *viz*., Einkorn (highly aphid resistant), Azadi (aphid resistant), Ommid (aphid semiresistant), and Moghan2 (aphid susceptible), affected differently the coccinellid predator *Coccinella septempunctata*. Digestibility of aphids (by beetle), *S. graminum* fed on resistant plant genotypes is higher than those fed on susceptible plants because of the lighter weights and smaller sizes of the first. This phenomenon could result in faster ingestion of *S. graminum* by *C. septempunctata* on these resistant plants. It is also possible that some metabolites found differentially in Einkorn and Azadi genotypes may have affected *S. graminum* quality as a food for *C. septempunctata*.

Chapter ~ III

Materials and methods

Chapter III

MATERIALS AND METHODS

The present studies on "**TRI-TROPHIC INTERACTIONS OF HOST PLANTS, APHID, *Aphis craccivora* Koch. AND COCCINELLID BEETLE, *Cheilomenes sexmaculata* (Fabricius)**" was carried out at the Insectary, Department of Entomology, S.V. Agricultural College, ANGRAU, Tirupathi, Andhra Pradesh during 2014-15. All the materials and methods followed in this study were illustrated below.

3.1 MAINTENANCE OF STOCK-CULTURE OF APHIDS, *A. craccivora* Koch.

The nucleus culture of aphids was maintained under polyhouse condition (Plate 1) on a susceptible cowpea cultivar (CO-702) (Plate 2). All the plants used for experiments were grown in plastic pots of 23 cm diameter and 20 cm height. The plants with aphids were encaged in wooden box of 46 cm X 46 cm X 70 cm size with iron mesh on all sides (Plate 3). The initial populations of aphids were collected from the cowpea field of College Farm, S.V. Agricultural College, Tirupati. Staggered planting of cowpea was done for continuous supply of host plants for rearing aphids.

3.2 POT CULTURING OF HOST PLANTS (COWPEA, GROUNDNUT, COTTON, SUNFLOWER, GREENGRAM AND BLACKGRAM)

All the six host plants *viz.*, Cowpea (var.- GC-3), Groundnut (Var.- K-6), Cotton (Var.- Narasimha), Sunflower (Var.- DRSH-1), Greengram (Var.- LGG-410) and Blackgram (Var.- LBG-791) were grown in plastic pots during *Kharif* 2014-15 from August onwards (Plate 4a and 4b). The seeds were procured from RARS, Tirupati and RARS, Nandyal. All the host plants (cowpea- 35 to 40 DAS, groundnut 35 to 40 DAS, cotton 25 to 30 DAS, sunflower 35 to 40 DAS, greengram 35 to 40 DAS and blackgram 35 to 40 DAS) used in the experiment were at peak vegetative stage.

Plate 1. Overall view of polyhouse for growing different host plants

Planting dates of all host plants were so adjusted that they would attain equal physiological maturity (peak vegetative stage) at the time of experiment. The substrate used for growing plants was red soil: compost in 3:1 ratio in plastic pots of 23cm X 20cm. The seeds of the test plants were treated with fungicides (Mancozeb @ 2gKg^{-1}) to prevent onset of any fungal diseases. All the normal agronomical practices were followed for the pot culturing of plants.

3.3 STUDIES ON THE BIOLOGY OF APHIDS, *A. craccivora* Koch.

Biology of aphids *A. craccivora* was studied under laboratory conditions at 28±2^{o}C temperature and 75-80 per cent RH. The second or third opened fresh leaves of the host plants at the peak vegetative stage were used for studying the biology of aphids. Fresh leaves were taken in glass petri plates of 9 cm diameter lined with moist blotting paper (Plate 5). The first instar nymphs of aphids were released on to these excised leaves at the rate of one nymph per petri plate. The developmental characters of aphids were studied under binocular microscope (MAGNUS Stereoscopic binocular microscope Model MS 24 Alpha with objective (2x & 4x) and eyepiece 10x (F.N.22) having with in-built Light Stand (Incident : 6V15W Lamp / Transmitted : 5W Fluorescence Lamp). Observations were taken at every 12 hours duration, on moulting, change in instars, nymphal durations, nymphal mortality, adult longevity and adult fecundity. Fresh leaves were provided as and when required. The moisture content of the blotting papers was also maintained accordingly. A total of 20 replications per host plant were used in the study.

3.4 MORPHOMETRICS OF APHIDS, *A. craccivora* Koch.

Morphometrical observations of the aphids such as body length, body width, head capsule width, antennal length, cornicle length and caudal length were taken using ocular micrometry for all the nymphal instars and the adult of aphids reared on all the six host plants. A total of ten replications per host plant was used in the experiment and the data was expressed in millimeters.

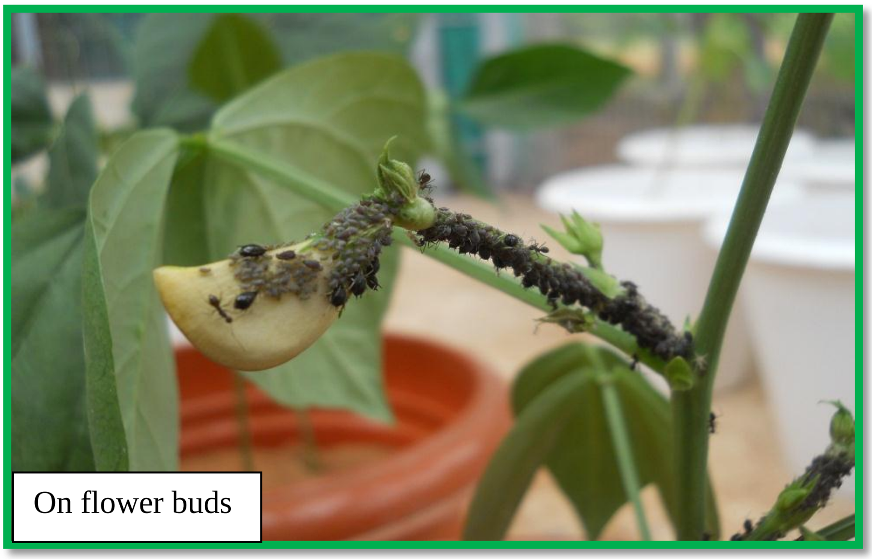


Plate 2. Establishment of aphids on different parts of susceptible host (Cowpea CO-702 variety)

Plate 3. Maintenance of Stock culture of *A. craccivora* in wooden cages

3.5 INTERACTION BETWEEN APHID BIOLOGY WITH PHYSICAL AND BIOCHEMICAL CHARACTERS OF HOST PLANTS

Trichome densities as the biophysical characters of host plants were recorded in the Department of Entomology, S.V. Agricultural College, Tirupati. The biochemical constituents such as protein, phenol, total free amino acids, total carbohydrates and total reducing sugar content were estimated at IFT, Regional Agricultural Research Station, Tirupati. The procedures and protocols are enlisted as below.

3.5.1 Biophysical characteristics

3.5.1.1 Trichome density

The trichome density was measured on the abaxial surfaces of the leaves of six host plants. Number of trichomes on 0.25 cm^2 cut leaf were counted and expressed as number of trichomes per 0.25 cm^2 leaf area.

3.5.2 Biochemical characteristics

The plant biochemical constituents such as protein content, total carbohydrates, total free amino acids, total phenol content and total reducing sugars of leaves of six host plants were estimated using the standard protocols. For each host plant, five replications were taken.

3.5.2.1 Estimation of protein

Estimation of protein content in fresh leaves of all the six host plants were done as per the methods of Lowry *et al.* (1951).

Preparation of reagents

a. Reagent-A: Reagent A was prepared by mixing sodium carbonate 2.0 per cent and sodium hydroxide 0.1 N with each other.

b. Reagent-B: Reagent B was prepared by mixing copper sulphate 0.5 per cent ($CuSO_4H_2O$) in 1.0 per cent sodium potassium tartarate.

a. Cowpea (GC-3)

b. Groundnut (K-6)

c. Cotton (Narasimha)

Plate 4a. Cowpea, groundnut and cotton grown in polyhouse


d. Sunflower (DRSH-1)


e. Greengram (LGG-410)


f. Blackgram (LBG-791)

Plate 4b. Sunflower, greengram and blackgram grown in polyhouse

c. 2 N sodium hydroxide: Eight g of sodium hydroxide was taken in a beaker and made upto 100 ml with distilled water.

d. Reagent-C: Alkaline copper solution was prepared by mixing 50 ml of reagent A and one ml of reagent B.

e. Reagent-D: Folin-ciocalteau reagent was mixed with distilled water at a ratio of 1:1.

Preparation of working standard

50 mg of bovine serum albumin was dissolved in distilled water and the final volume of stock solution was made upto 50 ml in a volumetric flask. From this, 10 ml was taken in another standard flask and volume was made upto 50 ml by adding 40 ml of distilled water. From the working standard, solutions of different concentrations of protein were prepared.

Procedure

A sample of 500 mg was weighed and ground in pestle and mortar with five ml of ten per cent trichloro acetic acid (TCA). The ground material was washed with 5 ml of cold TCA and kept in ice for 15 min. The material was centrifuged at 3500 rpm for 15 min and the supernatant was discarded and the precipitate was dissolved in 4 ml of 2 N NaOH. It was allowed to stand for overnight. Then it was centrifuged and supernatant was collected and finally the aliquot was made upto 10 ml.

From this aliquot, 0.1 ml of sample extract was pipetted out, to which 5 ml of reagent-C was added. The contents were mixed well and allowed to stand for 10 min. To which, 0.5 ml of reagent-D was added, mixed well and incubated for 30 min at room temperature in dark. The colour intensity was read at 660 nm.

Calculation

From the standard curve, concentration of protein expressed as mg/g in different entries were estimated.

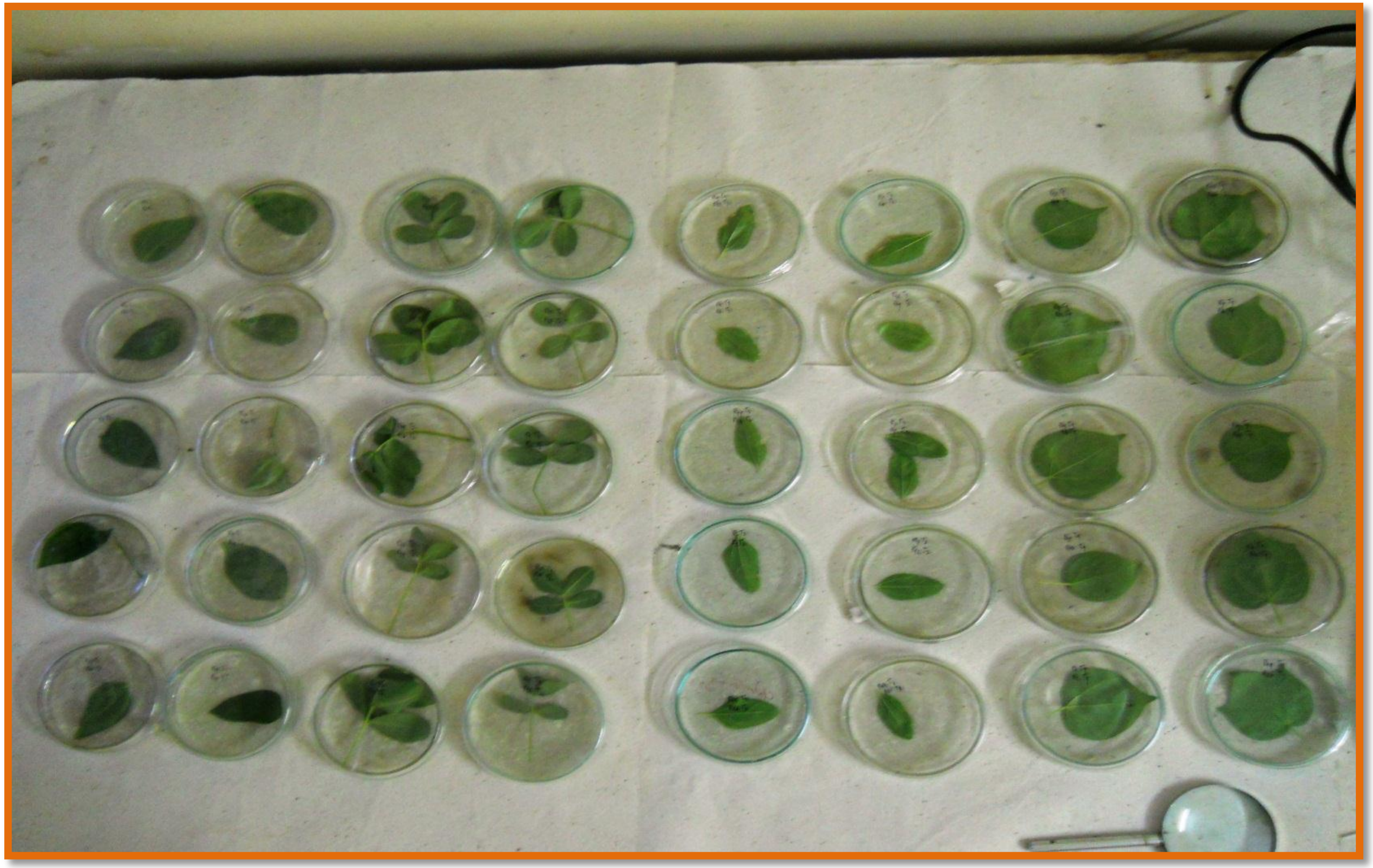


Plate 5. Study on the biologyof *A. craccivora* on excised leaves of different host plants

3.5.2.2 Estimation of phenols

The phenol content in fresh leaves of all the six host plants were estimated as per the method by Malick and Singh (1980).

Principle

Phenols react with phosphomolybdic acid in Folin-ciocalteau reagent in alkaline medium and produce blue coloured complex (Molybdenum blue).

Preparation of reagents

Ethanol 80.0 per cent was prepared by adding 80 ml of absolute alcohol in a beaker and made upto 100 ml by using distilled water.

Sodium carbonate 20.0 per cent was prepared by adding 20 g sodium carbonate in 100 ml of distilled water.

Preparation of working standards

100 mg catechol was dissolved in 100 ml of distilled water and diluted 10 times for preparing working standard. From the working standard different concentrations from 0.1 to 1.0 ml were taken.

Procedure

From each leaf sample 0.5 g of material was weighed and ground in a pestle and mortar, later ten times volume of 80.0 per cent ethanol was added. The homogenate was centrifuged at 10,000 rpm for 20 min. The supernatant was collected and residue was re-extracted with five times the volume of 80 per cent ethanol, centrifuged and the supernatants were pooled and evaporated to dryness. The dry residue was dissolved in five ml of distilled water and different aliquots 0.2 to 2.0 ml was pipetted to test tubes, making the volume in each tube to 3 ml by adding distilled water. Then 0.5 ml of Folin-ciocalteau reagent was added. After 3 min, 1 ml of 20.0 per cent sodium carbonate solution was added to each tube. The material was mixed thoroughly and tubes were placed in boiling water exactly for 1 min. The tubes were cooled and the absorbance was measured at 650 nm against a reagent blank in spectrophotometer. The standard curve was prepared by using different concentrations of catechol. Catechol concentrations on Y-axis and absorbance values on X-axis were taken for standard curve preparations.

Calculation

From the standard curve, concentrations of phenols in terms of mg per gram were expressed for the six host plants.

3.5.2.3 Estimation of total free amino acids

The total free amino acid content in leaves of six host plants were estimated as per the method by Moore and Stein (1948).

Principle

Ninhydrin, a powerful oxidizing agent, decarboxylates the α-amino acids and yields an intensely colored bluish purple product which is colorimetrically measured at 570 nm.

Preparation of reagents

a. Ninhydrin

In 500 ml of 0.2 M citrate buffer (pH 5.0) 0.8 g stannous chloride was dissolved. This solution was added to 20 g of ninhydrin dissolved in 500 ml methyl cellosolve (2 methoxyethanol).

b. 0.2M Citrate Buffer pH 5.0

Solution A (0.2M citric acid): solution A was prepared by mixing 4.2028 g of citric acid in 100 ml of distilled water.

Solution B (0.2M sodium citrate): solution B was prepared by mixing 5.882g of sodium citrate in 100 ml distilled water.

20.5 ml of Solution A was added to 29.5 ml of solution B and diluted to a total of 100 ml with distilled water this will come to pH 5.0.

c. Diluent Solvent

Equal volumes of water and *n*-propanol was mixed.

Preparation of working standard

In 50 ml of distilled water 50 mg of leucine was dissolved in a volumetric flask to prepare stock solution. 10 ml of this stock standard solution was diluted to 100 ml in another volumetric flask for preparing working standard solution. A series of volume from 0.1 to 1 ml of this standard solution gave a concentration range 10 μg to 100 μg.

Procedure

Extraction of amino acids

A sample of 500 mg ground in a pestle and mortar with a small quantity of acid-washed sand. To this homogenate, 5 to 10 ml of 80 per cent ethanol was added. Supernatant was saved after centrifugation and the extract was used for quantitative estimation of total free amino acids. Eighty per cent boiling ethanol was used for extraction when the tissue is tough.

Estimation of amino acids

To the 0.1 ml of extract, 1 ml of ninhydrin solution was added and then made the volume to 2 ml with distilled water. After heating the tube in boiling water bath for 20 min, 5 ml of diluent was added and the contents were mixed well. After 15 min intensity of purple color against a reagent blank in a colorimeter at 570 nm was read. The colour was stable for 1 h The reagent blank was prepared as above by taking 0.1 ml of 80 per cent ethanol instead of extract.

Calculation

From the standard curve, concentrations of total free amino acids in terms of mg per gram were expressed for the six host plants.

3.5.2.4 Estimation of total soluble sugars (TSS) (= total carbohydrates)

Estimation of total carbohydrates in the fresh leaves of all the six host plants were done as per the method by Hedge and Hofreiter (1962).

Principle

Carbohydrates are first hydrolyzed into simple sugars using dilute hydrochloric acid. In hot acidic medium glucose is dehydrated to hydroxymethyl furfural. This compound forms a green coloured product with anthrone at an absorption maximum at 630nm.

Preparation of reagents

2.5N HCl: 21.4 ml of commercial HCl was added to 78.6 ml of distilled water. **Anthrone reagent:** 200 mg anthrone was dissolved in 100 ml of ice cold 95 per cent H_2SO_4. It should be prepared freshly before use.

Preparation of working standards

To prepare standard glucose stock 100 mg of glucose was dissolved in 100 ml of distilled water in a volumetric flask. 10ml of stock was diluted to 100 ml in a volumetric flask to prepare working standard. After adding few drops of toluene it was stored in refrigerated condition.

Procedure

A sample of 100 mg was taken into boiling tube, to which 5 ml of 2.5 N HCl was added. Then the sample was hydrolysed by boiling on mantle heater for 3 hours. After the sample was cooled to room temperature. It was neutralised with solid sodium carbonate until effervescence ceases and volume in the flask was made up to 100 ml with distilled water. The sample was spun down once at 5000 rpm in a centrifuge. The supernatant was collected in a conical flask and aliquots of 0.5 and 1.0 ml were used for estimation. The standards were prepared by using the 0, 0.2, 0.4, 0.6, 0.8 and 1ml of the working standard where 0 served as blank. The volume was made up to 1 ml in all tubes including sample tubes with distilled water. Then 4 ml of anthrone reagent was added and heated for eight minutes in a boiling water bath. The contents in the tubes was cooled rapidly and the green to dark green colour was read at 630 nm.

Calculation

Standard graph plotted by using the concentration of the standard on the X-axis versus absorbance on Y-axis. From the graph the amount of carbohydrate present in the sample tube was calculated and expressed in percentage.

3.5.2.5 Estimation of reducing sugars

Reducing sugar content includes some of the reducing sugars such as glucose, galactose, lactose and maltose. The method by Somogyi (1952) was used for estimating reducing sugars in the present study.

Preparation of reagents

Reagent A was prepared by mixing 4 ml of copper sulphate solution (15 g of $CuSO_4$ dissolved in a small volume of distilled water and one drop of H_2SO_4 was added, and the volume was made up to 100 ml) and 96 ml of alkaline copper tartarate reagent (2.5 g anhydrous Na_2CO_3, 2 g of Na_2HCO_3, 2.5 g of potassium sodium tartarate and 20 g of anhydrous sodium sulphate were dissolved in 80 ml water and made upto 100 ml in a volumetric flask). Reagent B was prepared by dissolving 2.5 g of ammonium molybdate in 45 ml of distilled water and then by adding 2.5 ml H_2SO_4. 0.3 g of disodium hydrogen arsenate ($Na_2HSO_4.7H_2O$) was dissolved in 25 ml distilled water separately, and both solutions were mixed and placed in an incubator at 37°C for 24 to 48 hours.

Preparation of working standards

In 100 ml of distilled water 100 mg of glucose was dissolved in a volumetric flask to prepare standard glucose stock. Ten ml of stock was diluted to 100 ml, in a volumetric flask to prepare working standard.

Procedure

100 mg of sample was weighed and grinded with mortar and pestle. Sugars were extracted with five ml of hot 80 per cent ethanol twice. The extract

was centrifuged at 3500 rpm for 10 minutes. Supernatant was collected and the ethanol was evaporated by keeping the test tubes in a water bath at 80°C for 3 to 4 hrs. Sugars that were collected at the base of the test tube were dissolved with 5 ml distilled water and thoroughly mixed. Aliquots of 0.5 ml of sample were pippeted out in separate test tubes and the volume was made up to one ml with distilled water. One ml of reagent A was added to the sample and placed in boiling water bath for 10 minutes. After cooling the test tubes, one ml of reagent B was added and the volume was made up to eight ml with distilled water.

Calculation

The absorbance of the solution was measured in a spectrophotometer at 620 nm. The amount of reducing sugars was estimated using a standard graph prepared with glucose and expressed in percentage.

3.6 MAINTAINANCE OF NUCLEUS CULTURE OF COCCINELLID BEETLE, *C. sexmaculata* (Fab.)

The nucleus culture of *C. sexmaculata* was mentained in laboratory, at Insectary, Department of Entomology, S.V. Agricultural College, Tirupati. Initially the pupal stages were mass collected from the crop cafeteria of Insectary, S.V. Agricultural College and also from the research fields of College Farm. These pupae were kept in plastic boxes of 9cmX14cm. About seven plastic jars containing emerged adults were maintained in laboratory throughout the experiments (Plate 6). Nymphs and adults of aphids were provided continuously to maintain the populations of coccinellid beetles.

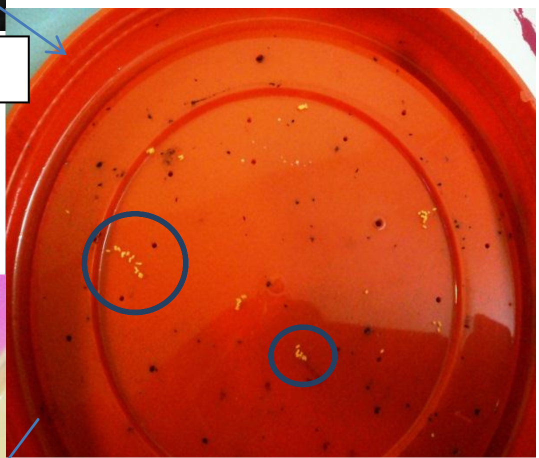
3.7 STUDIES ON BIOLOGY OF *C. Sexmaculata* (Fab.) FED ON APHIDS REARED ON SIX DIFFERENT HOST PLANTS

The biological parameters of coccinellid beetle, *C. sexmaculata* that were fed on aphids (*A. craccivora*), reared on different host plants, were studied. Individual eggs of lady bird beetle from the stock culture were taken in a small plastic container of 7cmX4cm and were provided with aphids reared on six different host plants. Once egg hatched, the grubs were provided with third and

Collected pupae of *C. sexmaculata* from field

Rearing of emerged adults in plastic jars

Mating of adults prior to oviposition



Eggs laid under surface of lid

Rearing of grubs with aphid infested cowpea twigs

Plate 6. Stoke culturing of *C. sexmaculata* in laboratory

fourth instar nymphs of aphids reared on six different host plants. All the biological parameters such as duration of egg stage, instar durations, pre-pupal stage, pupal stage, adult longevity, sex ratio etc. of lady bird beetle were taken. A total of five replications per host plant (total six hosts) were used in the present study.

3.7.1 Egg stage

The day from egg laying to the day to hatching of first instar grub were considered as the duration of egg stage.

3.7.2 Grub stage

From the day of hatching of egg, the grubs of coccinellid beetle were provided with sufficient amount of aphids that were reared on six different host plants. For the survival of the aphids inside the boxes small pieces of leaves of respective host plant were also provided and the leaves were kept fresh by lining the boxes with moist filter paper. The time from hatching of first instar grub to the final pre-pupal stage were considered as the total larval duration. Duration of every instars of grub were also measured by observing the moulted skins of the next grub stages.

3.7.3 Pre-pupal stage

The duration of pre-pupal stage were studied from the day of cessation of feeding till the pupation and were expressed in days.

3.7.4 Pupal stages

The duration of pupation to the adult emergence was considered as the duration of pupal stage of the beetle and were expressed in days.

3.7.5 Adult stage

From the day of adult emergence till the death was considered as the adult longevity. Other parameters such as male:female ratio, pre-oviposition periods, oviposition periods, post-oviposition periods and fecundity were also studied.

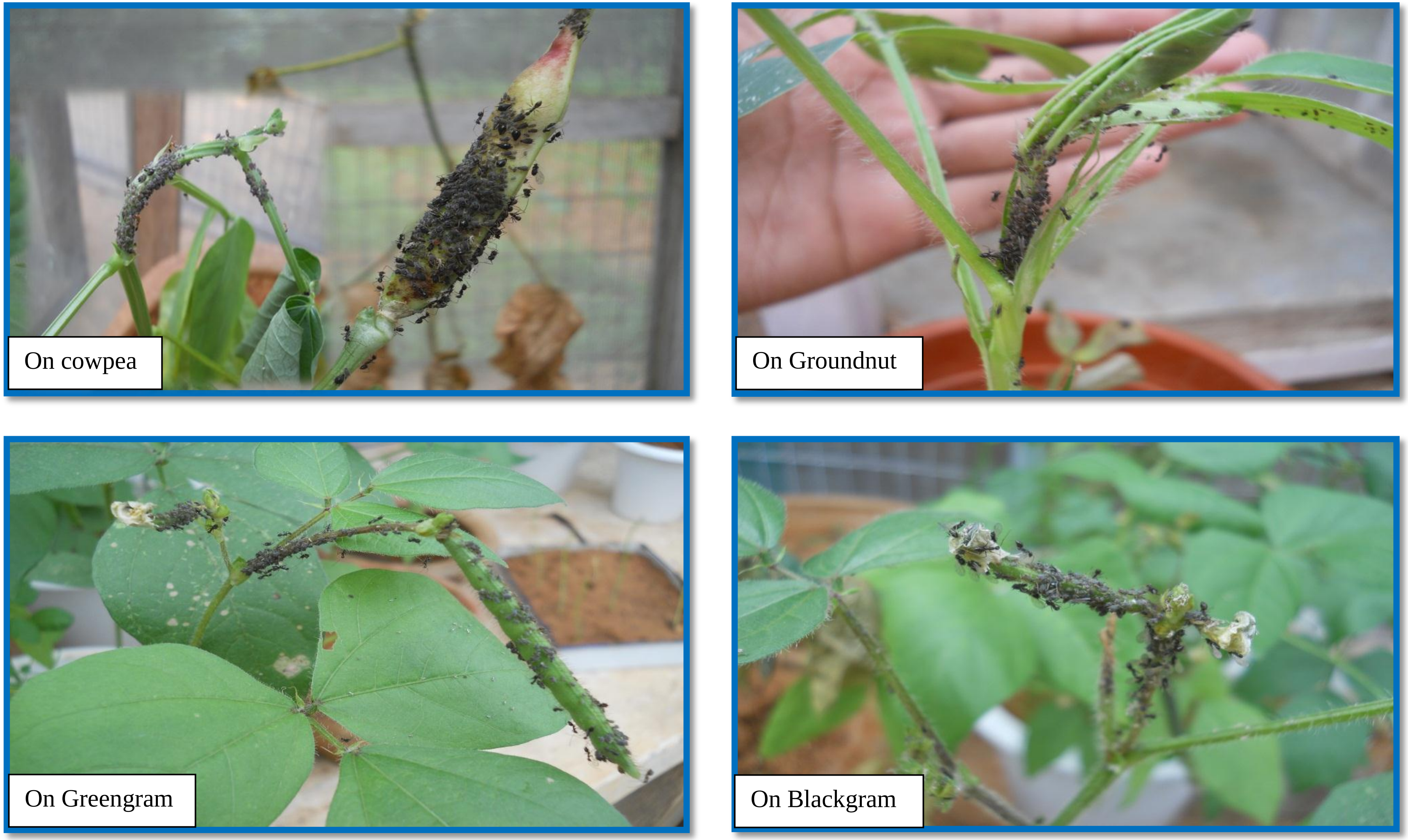


Plate 7. Rearing of *A. craccivora* on different host plants

3.8 STUDIES ON FEEDING POTENTIALITY OF *C. sexmaculata* FEEDING ON APHIDS REARED ON SIX DIFFERENT HOST PLANTS:

The feeding potentiality of *C. sexmaculata* was studied on aphids reared on six different host plants. The feeding potentiality was studied for both the grub and adult stages. The values were expressed in no. of aphids consumed per day and the mean total no of aphids consumed for the both grub and adult. Aphids were reared in large numbers on different host plants (cowpea, groundnut, cotton, sunflower, greengram and blackgram) (Plate 7). The newly hatched first instar grubs were taken in small plastic container and were provided with only third and fourth instar nymphs of *A. craccivora* (Plate 8). Daily known numbers of aphids were given to the grubs and after 24 hrs. the live aphids were counted and the total number of aphids consumed by the grubs were determined. Every time fresh nymphs of aphids were replaced by old ones. For the survival of aphids a small piece of leaf respective host plant were given in the container.

The same procedure was followed while studying the feeding potentiality of the adult beetle. The study was continued till the death of the adult beetle.

3.9 ANALYSIS OF DATA:

The unitless data were transformed by square root transformations whereas; the percentage data were transformed by angular transformations. All the data were subjected to ANOVA and DMRT analysis by using SPSS 13.0 software package.

Plate 8. Feeding potential study of *C. sexmaculata*

Chapter ~ IV

Results and Discussion

Chapter IV

RESULTS AND DISCUSSION

This chapter includes the results of the investigation regarding the tri-trophic interactions of six host plants; aphid *A. craccivora* Koch and the coccinellid beetle *C. sexmaculata* (Fab.). The details regarding the biology and morphometric variations of aphids, host plant characters, variation in biology and feeding potentiality of coccineliid beetles with respect to aphids reared on different host plants are presented in this chapter.

4.1 BIOLOGY OF *A. CRACCIVORA* ON SIX DIFFERENT HOST PLANTS

The biology and morphometrics of *A. craccivora* was studied in laboratory conditions of 28±2^{o}C temperature and 75-80 per cent RH. During the biology study, a total four instars were noticed. The experiment was carried out on excised leaves of six host plants as described under materials and methods. The mature adult aphid reproduced parthenogenetically and gave birth to live young nymphs. Total four nymphal instars were observed (Plate 9). The nymphs were dull greyish, lightly powdered and covered with wax. After the nymphal developmental period, they were coverted into either apterous or alate adult forms. The details of nymphal developmental and adult longevity periods are presented in Table 4.1a and 4.1b.

4.1.1 First instar

The freshly laid nymphs were light green in colour, transparent with light pigmentation. The mean duration of first instar of aphid varied among all the host plants. The duration was shortest (19.20±6.19 h) on both greengram and blackgram followed by sunflower (20.40±5.79 h). The nymphal duration was longest, when reared on cowpea (30.00±8.48 h) which was on par with nymphal period on groundnut and cotton (27.60±5.79 h and 27.60±8.09 h respectively).

Biology of aphids (*A. craccivora* Koch.) on excised leaves of different host plants.

Table 4.1a Nymphal Developmental periods (in hours) of aphids (*A. craccivora*) on different host plants.

Host plants	First instar ± S.D.	Second instar ± S.D.	Third instar ± S.D.	Fourth instar ± S.D.	Total nymphal duration±S.D.	% Nymphal mortality ± S.D.
Cowpea	30.00^{b}±8.48	24.00^{ab}±13.85	26.40^{a}±5.05	24.00^{ab}±8.00	104.40^{b}±8.09	0.00^{a}±0.00 (0.00)
Groundnut	27.60^{b}±5.79	34.80^{cd}±8.85	21.60^{a}±2.99	19.20^{a}±8.39	103.20^{ab}±14.08	20.00^{a}±42.16 (18.00)
Cotton	27.60^{b}±8.09	16.80^{a}±6.19	24.00^{a}±0.00	24.00^{ab}±0.00	92.40^{a}±9.87	100^{b}±0.00 (90.00)
Sunflower	20.40^{a}±5.79	30.00^{abc}±6.32	36.00^{b}±0.00	24.00^{ab}±0.00	110.40^{b}±11.02	100^{b}±0.00 (90.00)
Greengram	19.20^{a}±6.19	39.60^{d}±5.79	38.40^{b}±9.46	27.60^{b}±5.79	124.8^{c}±10.11	20.00^{a}±42.16 (18.00)
Blackgram	19.20^{a}±6.19	39.60^{d}±5.79	34.80^{b}±15.44	30.00^{b}±8.48	123.6^{c}±18.80	20.00^{a}±42.16 (18.00)
Grand Mean±S.E.	24.00±1.02	30.8±1.49	30.2±1.35	24.8±0.89	109.8±2.15	43.33±6.45 (39.00)

- Values followed by same letter are not significantly different at 0.05 level as per DMRT
- Values in the parenthesis are angular transformed value
- In case of cotton and sunflower the values are cumulative survival periods of first, second, third and fourth instar nymphs of aphids.

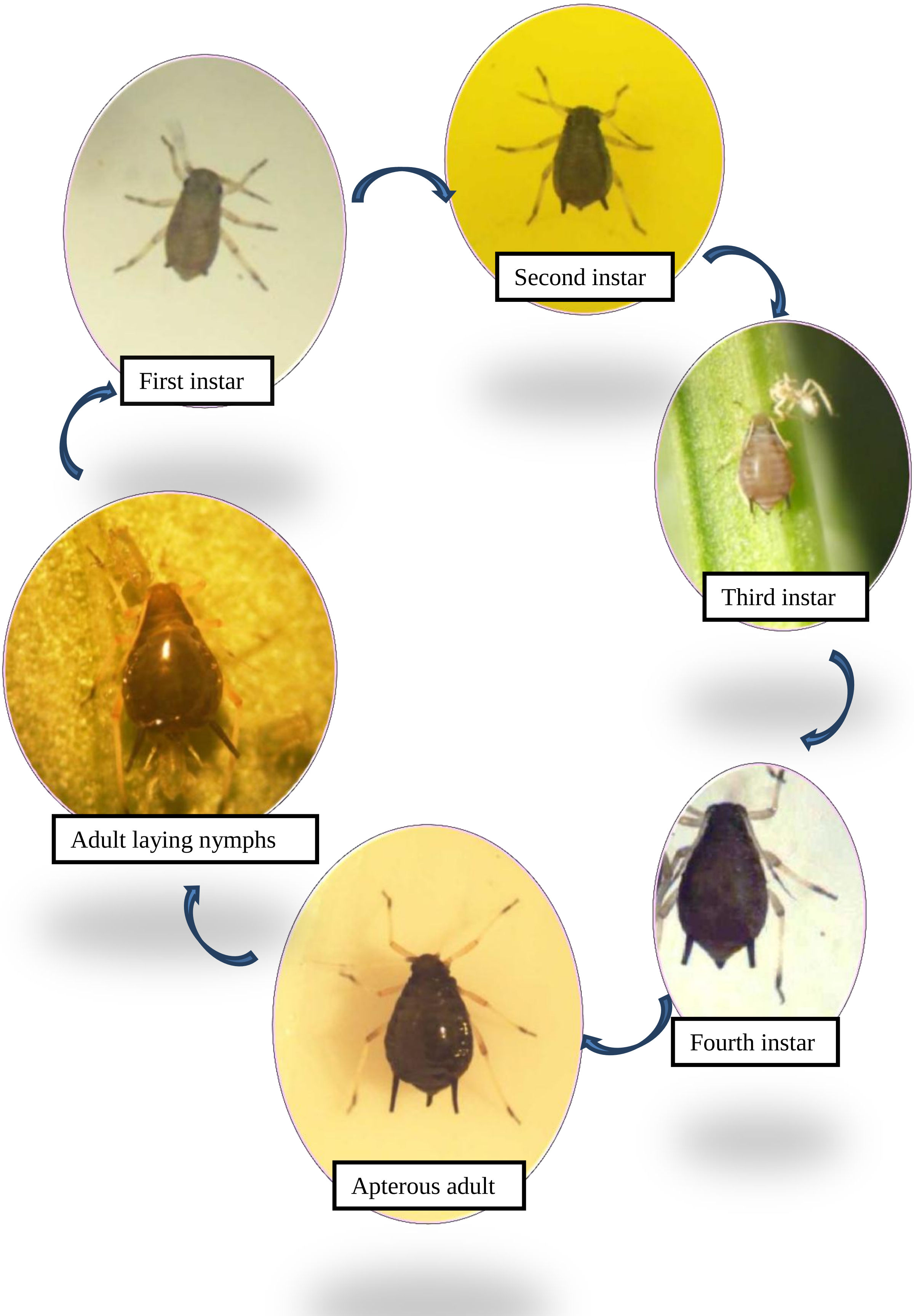


Plate 9. Different life stages of *A. craccivora*

4.1.2 Second instar

During second instar the nymphs turned to light green to pale grey colour with powdery waxy coating. The duration of second instar was shortest, when reared on cotton (16.80±6.19 h) which was on par with nymphal duration on cowpea (24.00±13.85 h) and sunflower (30.00±6.32 h). The duration was longest when aphids were reared on both greengram and blackgram (both 39.60±5.79 h), followed by groundnut (27.60±5.79 h).

4.1.3 Third instar

During third instar the nymphs got more pigmentation with powdery wax coating. Tip and base segments of the antennae became darker as compared to other segments. The duration of third instar was shortest, when aphids were reared on groundnut (21.60±2.99 h) followed by cotton (24.00±0.00 h), cowpea (26.40±5.05 h). The nymphal duration was longest, when aphids were reared on greengram (38.40±9.46 h) followed by sunflower (36.00±0.00 h) and blackgram (34.80±15.44 h).

4.1.4 Fourth instar

The duration of the fourth instar was shortest on groundnut (19.20±8.39 h) followed by cotton (24.00±0.00 h), sunflower (24.00±0.00 h) and cowpea (24.00±8.00 h). Longest nymphal duration was observed, when aphids were reared on blackgram (30.00±8.48 h), followed by greengram (27.60±5.79 h).

4.1.5 Total nymphal duration

In the present investigations, *A. craccivora* had longer nymphal duration when reared on greengram & blackgram (124.8±10.11 hr and 123.6±18.80 hr respectively) (significantly different) followed by sunflower (110.40±11.02 h), cowpea (104.40±8.09 h) and groundnut (103.20±14.08 h) (significantly different). The survival periods of first, second, third and fourth instar nymphs of aphids on cotton and sunflower ranged from 16.00 to 36.00 h after release. However, the nymphs have entered into the next instar by the time of getting mortality.

Srikanth and Lakkundi (1988) reported that nymphal period of *A. craccivora* was 4.84 days (~116 h), 6.67 days (~160 h), 6.43 days (~154 h) and 5.19 days (~124 h) when reared on cowpea, groundnut, greengram and blackgram respectively. Purnima Das Dutta (1999) reported that the nymphal development of *A. craccivora* varied from 5.00 days to 6.75 days on greengram.

4.1.6 Percentage nymphal mortality

While studying the nymphal mortality it was observed that Out of the 20 aphids (replicates) reared on excised leaves of the host plants, very few aphids reached the stage of post nymphal development (adult).

Aphids reared on cotton and sunflower though completed the nymphal development, could not become parthenogenetically active adults, claiming 100 per cent nymphal mortality. About 20 per cent nymphal mortality was observed when aphids were reared on groundnut, greengram and blackgram (on par with each other) (Fig. 4.1).

No nymphl mortality was observed when aphids were reared on excised leaves of cowpea giving it the status of most preferred host plants; and with 100 per cent nymphal mortality, cotton was given the status of least preferred or poor host.

4.1.7 Post nymphal developmental periods

The nymphs attained the stage of adulthood, after completing final moult of fourth instar. Adults were small and were shiny black in colour dorsally, including black cylindrical siphunculus and cauda (tail). The body was ovoid in shape. The different growth parameters such as pre-ovipostion, oviposition, post-oviposition, adult longevity, total life span and fecundity were expressed in hours and are presented in Table 4.1b.

Table 4.1b Post nymphal developmental periods (in hours) of aphids (*A. craccivora* Koch.) on different host plants.

Host plants	Pre-oviposition period±S.D.	Oviposition period±S.D.	Post-oviposition period±S.D.	Adult Longivity±S.D.	Total life span±S.D.	Fecundity (in no.)±S.D.
Cowpea	14.4^{a}±5.05	188.40^{c}±28.87	28.80^{b}±12.89	231.60^{b}±40.41	336.00^{c}±37.94	52.00^{b}±10.92 (7.24)
Groundnut	15.00^{a}±5.55	85.50^{a}±11.89	25.50^{ab}±7.69	100.80^{a}±54.61	204.00^{b}±57.96	21.12^{a}±2.64 (3.95)
Cotton	-	-	-	-	-	-
Sunflower	-	-	-	-	-	-
Greengram	15.00^{a}±5.55	96.00^{b}±62.51	13.50^{ab}±10.01	99.60^{a}±77.36	224.40^{b}±81.98	12.62^{a}±8.38 (2.92)
Blackgram	22.50^{b}±10.01	75.00^{ab}±63.74	10.50^{a}±10.01	86.40^{a}±73.27	210.00^{b}±66.03	9.87^{a}±8.67 (2.54)
Grand Mean±S.E.	16.58±1.24	115.76±11.20	20.11±2.19	152.47±12.13	196.20±12.26	25.55±3.34 (3.11)

Values followed by same letter are not significantly different at 0.05 level as per DMRT

Values in the parenthesis are square root transformed values

4.1.7.1 Pre-ovipostion period

No significant differences were observed regarding pre-oviposition period, when aphids reared on excised leaves of cowpea (14.4±5.05h), groundnut (15.00±5.55 h) and greengram (15.00±5.55 h). Longest pre-oviposition periods were observed when aphids were reared on blackgram (22.50±10.01 h) (significantly different).

4.1.7.2 Oviposition period and fecundity

Oviposition period was longest (188.40±28.87 h) when aphids were reared on cowpea, followed by greengram (96.00±62.51 h) and groundnut (85.50±11.89 h) (significantly different). Shortest ovipositional period was observed, when aphids were reared on blackgram (75.00±63.74 h) (on par with that of greengram).

On the excised leaves, adult aphids laid nymphs both on adaxial and abaxial leaf surfaces including the petiole regions.

Aphids reared on cowpea laid highest number of nymphs (52.00±10.92) (significantly different). Lowest number of nymphs were laid, when aphids were reared on blackgram (9.87±8.67), followed by greengram (12.62±8.38) and groundnut (21.12±2.64) (Fig. 4.2).

The longer oviposition period of aphids reared on cowpea, also reflected on high fecundity of adult aphids when they were reared on cowpea, giving it the status of the most preferred host plant.

The highest fecundity of aphids reared on cowpea, observed in the present investigation were in concurrence with the findings of Angayarkanni and Nadarajan (2008) who reported the fecundity of *A. craccivora* on cowpea as 53.02 per female. The results on fecundity of *A. craccivora*, reared on groundnut was closely supported by Srikanth and Lakkundi (1988) who reported the fecundity of *A. craccivora* on groundnut as 16.8 per female.

4.1.7.3 Post-oviposition period

Post-oviposition periods were considered as the period from the date of cessation of laying nymphs, till the date of death of adult. Post-oviposition period was shortest, when aphids were reared on blackgram (10.50±10.01 h), followed by greengram (13.50±10.01 h) and groundnut (25.50±7.69 h). Longest post ovipositional period was observed, when aphids were reared on cowpea (28.80±12.89 h) (on par with that of greengram and groundnut).

4.1.7.4 Adult longevity and Total life span

Adult longevity was highest on cowpea (231.60±40.41 h) (significantly different) followed by groundnut (100.80±54.61 h), greengram (99.60±77.36 h) and blackgram (86.40±73.27 h).

On cotton and sunflower aphids could complete only the nymphal developmental period and died before reaching the stage of adulthood.

When aphids were reared on cowpea, the total lifespan was longest (336.00±37.94 h) and the aphids also gave birth to higher number of nymphs (52.00±10.92).

Similar developmental durations, were observed by Angayarkanni and Nadarajan (2008), who reported that the aphids had nymphal period, pre-reproductive period, reproductive period, post-reproductive period and adult longevity of 7.6 days, 4.53 days, 6.57 days, 2.03 days and 13.39 days respectively on cowpea.

From the above observations, it was found that *A. craccivora* biology varied among all the tested host plants with respect to all the biological parameters. The total nymphal duration of *A. craccivora* was significantly longer, when reared on greengram and blackgram. It is generally believed that a resistant cultivar reduces the vigour of insect pest, prolonging its life-cycle hence making it more vulnerable to natural enemies (Dhaliwal and Dilwari, 1993). The longer duration of aphids on greengram and blackgram (not significantly different), and sunflower could be due to low nutrient status of these host plants which could have prolonged the aphid nymphal period.

From the results (Table 4.1a) it was also found that nymphal duration was shortest, when aphids were reared on cotton, giving cotton the status of preferred host. However from the percentage nymphal mortality data (Table 4.1a), it was found that though the nymphal duration was shortest on cotton and Sunflower, the nymphs could never reach the stage of adulthood (100 per cent nymphal mortality) on cotton and sunflower giving them the status of least preferred host.

From the oviposition data it was clear that the aphid reared on cowpea laid highest number of eggs and also had longest oviposition period (Table 4.1b) as compared to other host plants. The nutritive status and other host biochemical characters of cowpea might have influenced the high fecundity of aphids.

Based on the overall results from the present investigations, we can conclude that the performance of aphid *A. craccivora* were in the order of (most preferred to least preferred) cowpea > groundnut > greengram > blackgram > sunflower > cotton.

The outcome of the present investigations *i.e.*, cowpea as the most preferred host plant for *A. craccivora* has been supported by following workers. Srikanth and Lakkundi, (1988) reported that average nymphal period, adult longevity and duration of total life cycles (in days) of *A. craccivora* as 4.84 days, 10.42 days and 15.26 days respectively when reared on cowpea. The same durations were 6.67 days, 5.25 days and 11.92 days respectively when reared on groundnut, 6.43 days, 6.04 days and 12.47 days respectively when reared on greengram and 5.19 days, 5.15 days and 10.34 days respectively when reared on blackgram.

Kaakeh and Dutcher (1993) working on different host plants of *A. craccivora* reported that the mean total fecundity, fecundity rate, and intrinsic and finite rates of increase were higher on cowpea than other host plants. Sunil *et al.* (1998) also reported that out of three host plants *viz.*, cowpea, lablab and pigeon pea, cowpea was the most preferred host.

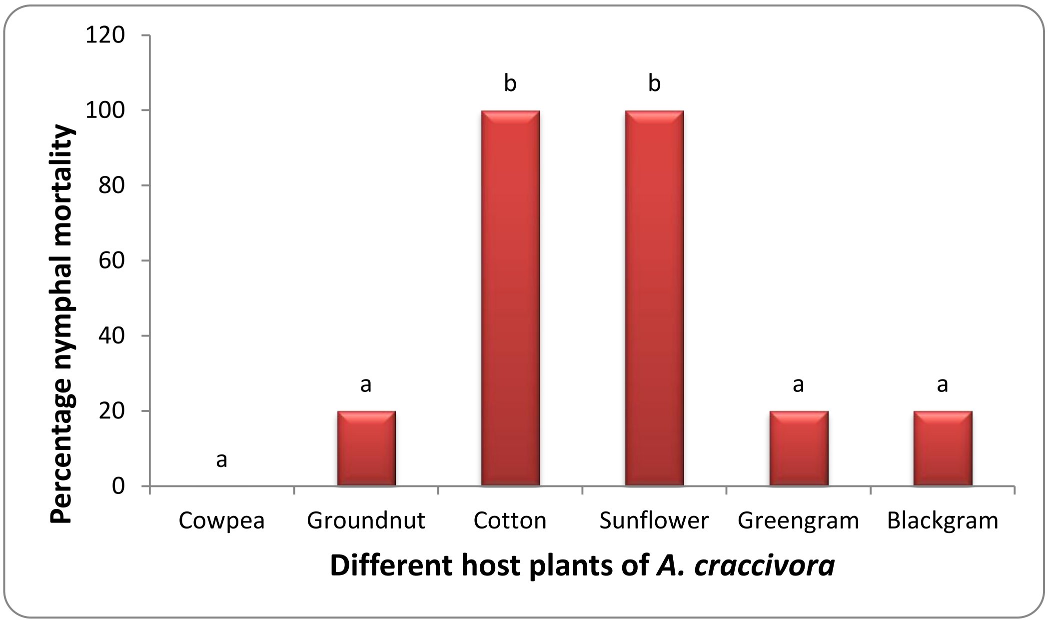


Fig. 4.1. Percentage nymphal mortality of *A. craccivora* reared on different host plants
(Bars followed by same letter are not significantly different)

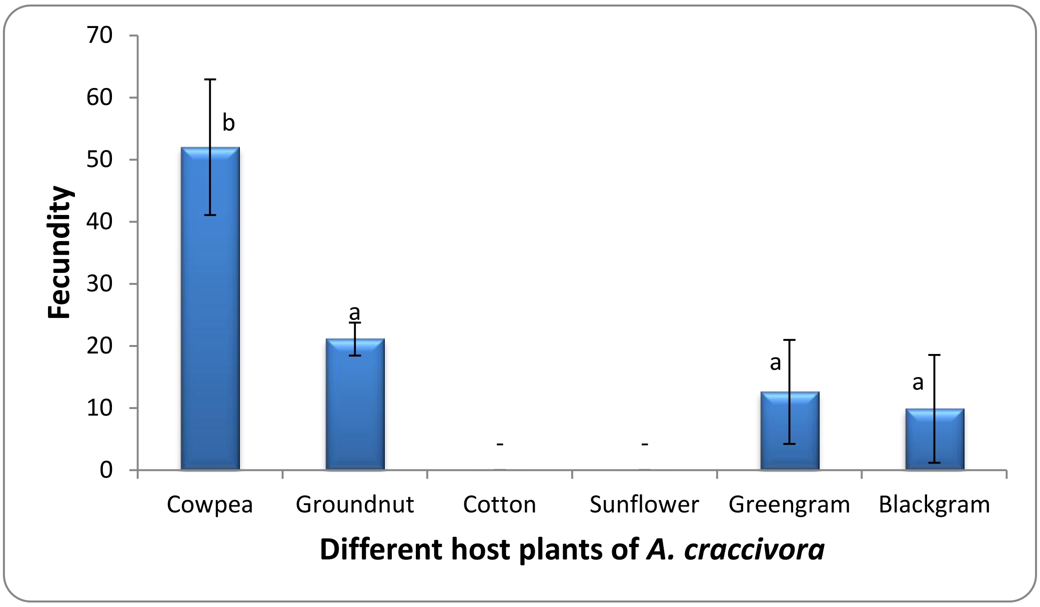


Fig. 4.2. Fecundity of *A. craccivora* reared on different host plants
(Bars followed by same letter are not significantly different)

Angayarkanni and Nadarajan (2008) reported that the aphid *A. craccivora* had mean fecundity of 53.02 per female with an average rate of nymph production of 8.07 per day per aphid when reared on cowpea.

4.2 MORPHOMETRICS OF DIFFERENT STAGES OF DEVELOPMENT OF *A. CRACCIVORA* ON SIX DIFFERENT HOST PLANTS

Morphometrics of different instars and adult stage of *A. craccivora* were taken with respect to body length, body width, antennal length, head capsule width and cornicle length. The detailed data are presented in Table 4.2a, Table 4.2b, Table 4.2c, Table 4.2d and Table 4.2e.

4.2.1 First instar

No significant difference were found in the morphometrics of first instar nymphs (body length, body width, antennal length, head capsule width and cornicle length) of aphids reared on different host plants.

4.2.2 Second instar

Body length of second instar nymphs was longest (0.91±0.02 mm) when aphids were reared on cowpea (significantly different) followed by greengram (0.83±0.03 mm), groundnut (0.80±0.01 mm) and blackgram (0.80±0.01 mm). Body width was also highest, when aphids were reared on cowpea (0.51±0.01 mm), followed by greengram (0.45±0.01 mm), groundnut (0.44±0.00 mm) and blackgram (0.44±0.00 mm).

No significant differences in antennal length and head capsule width were observed, when aphids were reared on different host plants (Table 4.2b).

The cornicle length was longest when aphids were reared on groundnut and blackgram (0.12±0.00 mm) (on par with each other). Shortest cornicle length was observed when aphids were reared on greengram (0.08±0.00 mm) followed by cowpea (0.10±0.00 mm) (not significantly different).

Table 4.2a. Morphometrics (mm) of first instars of *A. craccivora* Koch. reared on different host plants.

Host plants	Body length±S.D.	Body width±S.D.	Antennal length ±S.D.	Head capsule width±S.D.	Cornicle length±S.D.	Caudal length±S.D.
Cowpea	0.66^{a}±0.04	0.30^{a}±0.02	0.44^{a}±0.10	0.26^{a}±0.00	0.05^{a}±0.00	0.06^{a}±0.00
Groundnut	0.65^{a}±0.06	0.29^{a}±0.02	0.51^{a}±0.11	0.26^{a}±0.00	0.05^{a}±0.00	0.05^{a}±0.00
Greengram	0.65^{a}±0.04	0.29^{a}±0.02	0.42^{a}±0.09	0.26^{a}±0.00	0.04^{a}±0.00	0.06^{a}±0.00
Blackgram	0.65^{a}±0.06	0.29^{a}±0.02	0.51^{a}±0.11	0.26^{a}±0.00	0.05^{a}±0.00	0.05^{a}±0.00
Grand Mean±S.E.	0.65±0.00	0.29±0.00	0.45±0.02	0.26±0.00	0.05±0.00	0.06±0.00

Values followed by same letter are not significantly different at 0.05 level as per DMRT

Table 4.2b. Morphometrics (mm) of second instars of *A. craccivora* Koch. reared on different host plants.

Host plants	Body length±S.D.	Body width±S.D.	Antennal length±S.D.	Head capsule width±S.D.	Cornicle length±S.D.	Caudal length±S.D.
Cowpea	0.91^{b}±0.02	0.51^{b}±0.01	0.54^{a}±0.04	0.28^{a}±0.01	0.10^{a}±0.00	0.08^{ab}±0.01
Groundnut	0.80^{a}±0.01	0.44^{a}±0.00	0.50^{a}±0.01	0.29^{a}±0.00	0.12^{b}±0.00	0.06^{a}±0.00
Greengram	0.83^{a}±0.03	0.45^{a}±0.01	0.51^{a}±0.01	0.29^{a}±0.01	0.08^{a}±0.00	0.09^{b}±0.00
Blackgram	0.80^{a}±0.01	0.44^{a}±0.00	0.50^{a}±0.01	0.29^{a}±0.00	0.12^{b}±0.00	0.06^{a}±0.00
Grand Mean±S.E.	0.86±0.01	0.48±0.00	0.52±0.00	0.28±0.00	0.10±0.00	0.08±0.00

Values followed by same letter are not significantly different at 0.05 level as per DMRT

Table 4.2c. Morphometrics (mm) of third instars of *A. craccivora* Koch. reared on different host plants.

Host plants	Body length±S.D.	Body width ± S.D.	Antennal length±S.D.	Head capsule width±S.D.	Cornicle length±S.D.	Caudal length±S.D.
Cowpea	1.25^{a}±0.12	0.59^{b}±0.03	0.67^{b}±0.10	0.33^{a}±0.01	0.12^{a}±0.02	0.10^{a}±0.02
Groundnut	1.15^{a}±0.03	0.48^{a}±0.02	0.54^{a}±0.01	0.31^{a}±0.00	0.12^{a}±0.02	0.08^{a}±0.01
Greengram	1.17^{a}±0.06	0.53^{a}±0.02	0.54^{a}±0.02	0.32^{a}±0.02	0.12^{a}±0.03	0.07^{a}±0.01
Blackgram	1.15^{a}±0.03	0.48^{a}±0.02	0.54^{a}±0.01	0.31^{a}±0.00	0.12^{a}±0.02	0.08^{a}±0.01
Grand Mean±S.E.	1.20±0.02	0.54±0.01	0.60±0.02	0.32±0.00	0.12±0.00	0.09±0.00

Values followed by same letter are not significantly different at 0.05 level as per DMRT

Table 4.2d. Morphometrics (mm) of fourth instars of *A. craccivora* Koch. reared on different host plants.

Host plants	Body length±S.D.	Body width±S.D.	Antennal length±S.D.	Head capsule width±S.D.	Cornicle length±S.D.	Caudal length±S.D.
Cowpea	1.56^{c}±0.01	0.80^{c}±0.00	0.81^{c}±0.03	0.36^{b}±0.00	0.20^{b}±0.02	0.18^{b}±0.01
Groundnut	1.25^{a}±0.03	0.54^{a}±0.01	0.54^{a}±0.01	0.32^{a}±0.00	0.10^{a}±0.01	0.06^{a}±0.01
Greengram	1.40^{b}±0.01	0.72^{b}±0.01	0.71^{b}±0.01	0.32^{a}±0.01	0.15^{ab}±0.00	0.16^{b}±0.00
Blackgram	1.32^{ab}±0.02	0.55^{a}±0.01	0.58^{a}±0.00	0.33^{ab}±0.00	0.11^{a}±0.01	0.07^{a}±0.01
Grand Mean±S.E.	1.44±0.02	0.71±0.02	0.72±0.02	0.34±0.00	0.16±0.01	0.15±0.01

Values followed by same letter are not significantly different at 0.05 level as per DMRT

4.2.3 Third instar

Body length and body width was longest (1.25± 0.12; 0.59±0.03 mm), when aphids were reared on cowpea followed by greengram (1.17±0.06 mm; 0.53±0.02 mm) (significantly different). The shortest body length and width (1.15±0.03 mm; 0.48±0.02 mm), was observed when aphids were reared on groundnut and blackgram. Antennal length was longest (0.67±0.10 mm), when aphids were reared on cowpea (significantly different), followed by groundnut, greengram and blackgram (all 0.54±0.01 mm) (not significantly different).

No significant differences in head capsule width, cornicle length and caudal length were observed, when aphids were reared on different host plants (Table 4.2c).

4.2.4 Fourth instar

Body length was longest (1.56±0.01 mm), when aphids were reared on cowpea which was significantly different from other host plants. Shortest body length was found, when aphids were reared on groundnut (1.25±0.03 mm) followed by blackgram (1.32±0.02 mm), greengram (1.40±0.01 mm) (at par with that of blackgram). Body width was longest when aphids were reared on cowpea (0.80±0.00 mm) followed by greengram (0.72±0.01 mm) (significantly different). Shortest body width was observed when aphids were reared on groundnut (0.54±0.01 mm) followed by blackgram (0.55±0.01 mm) (not significantly different).

Antennal length was longest, when aphids were reared on cowpea (0.81±0.03 mm) (significantly different) followed by greengram (0.71±0.01 mm) (significantly different), blackgram (0.58±0.00 mm) and groundnut (0.54±0.01 mm). Longest head capsule width was noticed, when aphids were reared on cowpea (0.36±0.00 mm) (significantly different) followed by blackgram (0.33±0.00 mm), groundnut and greengram (0.32±0.00 mm) (not significantly different).

Table 4.2e. Morphometrics (mm) of Adult of *A. craccivora* Koch. growing on different host plants.

Host plants	Body length±S.D.	Body width±S.D.	Antennal length±S.D.	Head capsule width±S.D.	Cornicle length±S.D.	Caudal length±S.D.
Cowpea	$2.33^{b}\pm0.14$	$1.18^{c}\pm0.02$	$1.66^{b}\pm0.13$	$0.44^{c}\pm0.02$	$0.44^{b}\pm0.05$	$0.31^{c}\pm0.02$
Groundnut	$1.82^{a}\pm0.04$	$0.93^{a}\pm0.04$	$0.86^{a}\pm0.16$	$0.32^{a}\pm0.00$	$0.29^{a}\pm0.02$	$0.16^{a}\pm0.01$
Greengram	$1.96^{a}\pm0.15$	$1.08^{b}\pm0.06$	$1.50^{b}\pm0.08$	$0.40^{b}\pm0.03$	$0.37^{ab}\pm0.02$	$0.22^{b}\pm0.01$
Blackgram	$1.90^{a}\pm0.03$	$0.95^{a}\pm0.07$	$1.03^{a}\pm0.28$	$0.37^{b}\pm0.01$	$0.37^{ab}\pm0.02$	$0.19^{ab}\pm0.05$
Grand Mean±S.E.	2.11±0.05	1.09±0.02	1.42±0.07	0.41±0.01	0.39±0.01	0.25±0.01

Values followed by same letter are not significantly different at 0.05 level as per DMRT

Cornicle length was longest (0.20±0.02 mm), when aphids were reared on cowpea, followed by greengram (0.15±0.00 mm) (not significantly different). Shortest cornicle length was noticed on groundnut (0.10±0.01 mm) which was not significantly different from that of blackgram (0.11±0.01 mm). Longest caudal length was noticed, when aphids were reared on cowpea (0.18±0.01 mm) followed by greengram (0.16±0.00 mm) (not significantly different). Caudal length was shortest (0.06±0.01 mm), when aphids were reared on groundnut followed by blackgram (0.07±0.01 mm).

4.2.5 Adult

Maximum body length of adult was observed, when aphids were reared on cowpea (2.33±0.14 mm) (significantly different) followed by greengram (1.96±0.15 mm), blackgram (1.90±0.03 mm) and groundnut (1.82±0.04 mm). Longest body width (1.18±0.02 mm) was found, when aphids were reared on cowpea (significantly different), followed by greengram (1.08±0.06 mm), blackgram (0.95±0.07 mm) and groundnut (0.93±0.04 mm) (not significantly different).

Antennal length was longest on cowpea (1.66±0.13 mm) followed by greengram (1.50±0.08 mm) (both not significantly different), blackgram (1.03±0.28 mm) and groundnut (0.86±0.16 mm) (not significantly different). Head capsule width was longest, when aphids were reared on cowpea (0.44±0.02 mm) followed by greengram (0.40±0.03 mm) (significantly different) and blackgram (0.37±0.01 mm) (not significantly different). Shortest head capsule length was noticed, when aphids were reared on groundnut (0.32±0.00 mm) (significantly different from others).

Cornicle length was longest, when aphids were reared on cowpea (0.44±0.05 mm) followed by greengram and blackgram (0.37±0.02 mm). Shortest cornicle length was observed, when aphids were reared on groundnut (0.29±0.02 mm) (on par with that of greengram and blackgram). Longest caudal length was found, when aphids were reared on cowpea (0.31±0.02 mm) (significantly different) followed by greengram (0.22±0.01 mm), blackgram (0.19±0.05 mm) (not significantly different). Shortest caudal length was noticed, when aphids were reared on groundnut (0.16±0.01 mm) (on par with blackgram).In our present investigations, the body length of the adults varied from 1.82 mm on groundnut to 2.33 mm on cowpea and body width varied from 0.9m mm on groundnut to 1.18 mm on cowpea. Our present findings were in accordance with Usmani and Rafi (2009), who reported that apterus *A. craccivora* had a body length of 1.94 mm, width 1.28 mm, antennae 1.48 mm, siphunculus 0.42 mm and cauda 0.26 mm. Reddy *et al.* (1983) also reported that the body size of adult *A. craccivora* was highest (1.948 mm^2) on bean, followed by Arhar (var. T-21) (1.532 mm^2), Arhar (var. Bahar) (1.49 mm^2), Arhar (var. G-3) (1.43 mm^2), Arhar (var.Jyoti) (1.024 mm^2) and Lentil (var. JL-1) (0.873 mm^2) when reared on respective host plants.

In most of the observation seen above (Table 4.2a, b, c, d, e) body length, body width, head capsule width, cornicle length and antennal length was more when aphids were reared on cowpea. This clearly indicates that cowpea is the most preferred host plant for growth and development of aphid, *A. craccivora*, wherein aphids were bigger in size. Concurrently, aphids that were bigger when reared on cowpea, also had longer ovipositional periods and also gave birth to more number of young ones (Table 4.1b). This clearly indicates high nutritional status of cowpea for the growth and multiplication of aphid *A. craccivora*.

From the above observations, it was also found that shortest morphometrical measurements were observed, when aphids were reared on groundnut indicating low nutritional status of the host plant.

We can conclude from the above study, that the performance of aphid *A. craccivora* with regard to the morphometrical measurements were in the order of (most preferred to least preferred) cowpea > greengram = blackgram = groundnut.

4.3 HOST PLANT CHARACTERS

Both biophysical (Trichome density) and biochemical constituents (*viz*., protein content, total soluble sugar (TSS), phenol content, Free amino acids and

Table 4.3 Biophysical and biochemical characteristics of different host plants.

Host plants	Physical characteristics	Biochemical characteristics				
	Trichome density±S.D.	Protein±S.D. (mg/g)	TSS±S.D. (mg/g)	Phenols±S.D. (mg/g)	FAA±S.D. (mg/g)	Reducing Sugars±S.D. (mg/g)
Cowpea	0.00[a]±0.00 (1)	335.21[d]±29.58	13.04[b]±1.34	49.29[a]±17.04	5.68[d]±2.26	1.82[a]±0.38
Groundnut	17.3[b]±8.40 (4.45)	203.01[b]±38.32	7.49[a]±2.06	76.43[a]±29.22	3.49[b] ±0.82	1.96[a]±0.22
Cotton	265.9[c]±78.97 (18.12)	306.06[d]±71.92	5.53[a]±0.92	260.46[b]±31.43	1.24[ca]±0.54	2.58[b]±0.61
Sunflower	152.1[d]±42.89 (12.63)	139.53[a]±26.13	16.14[d]±1.76	92.97[a]±7.42	0.40[a]±0.41	3.15[c]±0.23
Greengram	78.8[e]±19.43 (8.89)	220.65[bc]±10.55	11.22[bc]±0.82	91.71[a]±20.28	4.04[db]±1.06	2.06[a]±0.08
Blackgram	86.7[e]±23.65 (9.52)	275.01[dc] ±76.73	10.06[c]±1.74	97.15[a]±50.58	2.32[bc]±0.47	2.21[ab]±0.09
Grand mean±S.E.	9.10±1.16	246.57±15.66	10.57±0.77	111.33±15.25	2.85±0.42	2.29±0.11

Values followed by same letter are not significantly different at 0.05 level as per DMRT
Values in parenthesis are square root transformed values

reducing sugar content) of host plants were studied with respect to performance of aphids and the results are presented in the Table 4.3.

4.3.1 Biophysical constituents

4.3.1.1 Trichome density

Numbers of trichomes present on abaxial leaf surfaces were counted (per 0.25 cm^2 leaf area) and are presented in Table 4.3.

The highest trichome density was found in case of cotton (265.9±78.97 hairs per 0.25 cm^2 leaf area) (significantly different), followed by sunflower (152.1±42.89) (significantly different), blackgram (86.7±23.65) and greengram (78.8±19.43). Least trichome density was found in case of cowpea (0.00±0.00) followed by groundnut (17.3±8.40) (both significantly different).

4.3.2 Biochemical constituents

Biochemical constituents *viz*., protein content, total soluble sugar, phenol content, Free amino acids and reducing sugar content of leaves of different host plants were estimated as per the protocols in section 3.5.2 of materials and methods, and are expressed in mg/g of fresh leaves and are presented in Table 4.3.

4.3.2.1 Protein content

Highest protein content (335.21±29.58 mg/g) was found in the leaves of cowpea followed by leaves of cotton (306.06±71.92 mg/g), leaves of blackgram (275.01 ±76.73 mg/g). Comparatively lowest protein content was detected in leaves of sunflower (139.53±26.13 mg/g) (significantly different) followed by groundnut (203.01±38.32 mg/g) and greengram (220.65±10.55 mg/g) (both not significantly different).

4.3.2.2 Total soluble sugar content (TSS)

Total soluble sugar content was highest in the leaves of sunflower (16.14±1.76 mg/g) (significantly different) followed by cowpea (13.04±1.34 mg/g) and greengram (11.22±0.82 mg/g). Least TSS content was detected in cotton (5.53±0.92 mg/g) and groundnut (7.49±2.06 mg/g) (both significantly different from others). In blackgram TSS content was 10.06±1.74 mg/g (on par with that of greengram).

4.3.2.3 Phenol content

Total phenol content was highest in the leaves of cotton (260.46±31.43 mg/g) (significantly different from others) followed by blackgram (97.15±50.58 mg/g), sunflower (92.97±7.42 mg/g), greengram (91.71±20.28 mg/g), groundnut (76.43±29.22 mg/g) and cowpea (49.29±17.04 mg/g) which are not significantly different.

4.3.2.4 Total free amino acids

Cowpea leaves were found to have highest quantity of total free amino acids (5.68±2.26 mg/g) followed by leaves of greengram (4.04±1.06 mg/g) and groundnut (3.49±0.82) (on par with greengram). Least quantity of total free amino acids were found in case of leaves of sunflower (0.40±0.41 mg/g), followed by cotton (1.24±0.54 mg/g) and blackgram (2.32±0.47 mg/g) (on par with greengram and cotton).

4.3.2.5 Total reducing sugars

Highest total reducing sugars were detected in leaves of sunflower (3.15±0.23 mg/g) followed by cotton (2.58±0.61 mg/g) (significantly different) and blackgram (2.21±0.09 mg/g). The lowest total reducing sugars were detected in the leaves of cowpea (1.82±0.38 mg/g), groundnut (1.96±0.22 mg/g) and greengram (2.06±0.08 mg/g) (on par with each other).

Table 4.4 Correlation study of different growth parameters of aphids and host plant characters (Biophysical and biochemical).

Growth parameters	Correlation	Host plant characters					
		Trichome density	Protein (mg/g)	TSS (mg/g)	Phenol (mg/g)	FAA (mg/g)	Reducing sugars (mg/g)
Nymphal duration	Pearson Correlation	-0.129	**-0.402***	0.215	**-0.399***	0.083	-0.072
Percentage Nymphal Mortality	Pearson Correlation	**0.682****	-0.279	-0.069	**0.408***	**-0.705****	**0.589****
Adult longevity	Pearson Correlation	**-0.752****	**0.435***	0.126	**-0.462***	**0.755****	**-0.555****
Fecundity	Pearson Correlation	**-0.799****	**0.443***	0.128	**-0.479***	**0.737****	**-0.563****
Total life span	Pearson Correlation	**-0.762****	0.360	0.161	**-0.522****	**0.757****	**-0.559****

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

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

4.4 Correlation study of different growth parameters of aphids and host plant constituents (biophysical and biochemical)

A statistical analysis was done to correlate the performance of aphids on different host plants with that of host plant constituents and the results are presented in Table 4.4 and 4.5.

4.4.1 Nymphal duration

Total nymphal developmental periods of *A. craccivora* was negatively correlated with total protein content (r = -0.402) and total phenol content (r = -0.399) of the host plants (both are significant at 0.05 level). Though the nymphal duration was negatively correlated with trichome density and reducing sugars (r = -0.129 and -0.072); positively correlated (r = 0.215 and 0.083) with TSS and FAA, they were not significant at 0.05 level.

The results of correlation studies were subjected to step wise regression analysis to find out the regression equations. Total nymphal durations could be explained by the multiple regression model

y = 145.47 +2.903(Trichome density) -0.081(Protein content) -0.0193(TSS) -0.192(phenol content) +2.774(FAA) -11.365(reducing sugar) (R^2 = 0.422).

According to the regression equation, influence of protein and phenol content of host plants on nymphal duration is up to 42 per cent (R^2 = 0.422) (Table 4.5).

4.4.2 Percentage nymphal mortality

Percentage nymphal mortality was positively correlated with trichome density (r = 0.682 at 0.01), total phenol content (r = 0.408 at 0.05), and total reducing sugar content (r = 0.589 at 0.01) of the host plants. Whereas, a negative correlation was observed between the percentage nymphal mortality with the total protein content (r = -0.279) and total soluble sugar content (r = -0.069) (not significant). Free amino acids content was negatively correlated (r = -0.705 at 0.01) with the percentage nymphal mortality.

The results of correlation studies were subjected to step wise regression analysis to find out the regression equations. Total percentage nymphal mortality could be explained by the multiple regression model

y = 30.574 +3.427(Trichome density) -0.022(Protein) -1.210(TSS) -0.120(Phenols) -8.209(FAA) +15.023(Reducing sugar) (R^2 = 0.593).

According to the regression equation, influence of trichome density, phenols, FAA and reducing sugar content of host plants on percentage nymphal mortality is up to 59 per cent (R^2 = 0.593).

4.4.3 Adult longevity

Duration of adult longevity of *A. craccivora* was negatively correlated with trichome density (r = -0.752, at 0.01), phenol content (r = -0.462 at 0.05), and reducing sugar content (r = -0.555 at 0.01) of the host plants. Total free amino acid content was positively correlated (r = 0.755 at 0.01) with the adult longevity of *A. craccivora*. Whereas, total protein content were significantly positively correlated (r = 0.435) with adult longevity, but total soluble sugar content were positively correlated (r = 0.126).

The results of correlation studies were subjected to step wise regression analysis to find out the regression equations. Adult longevity could be explained by the multiple regression model

y = -7.402 -10.941(Trichome density) +0.342(Protein content) +3.244(TSS) +0.241(Phenol content) +12.787(FAA) +5.689(Reducing sugars) (R^2 = 0.738).

According to the regression equation, influence of trichome density, phenols, FAA and reducing sugar content of host plants on adult longevity is up to 73 per cent (R^2 = 0.738).

4.4.4 Fecundity

Fecundity of *A. craccivora* in all host plants was positively correlated with total protein content (r = 0.443, at 0.05), total free amino acids (r = 0.737, at 0.01). Fecundity was also negatively correlated with trichome density (r = -0.799,

Table 4.5 Regression model developed for growth parameters of *Aphis craccivora* Koch. affected by host plant characters.

Growth parameters	Regression Equation	R^2 value
Total nymphal duration	y = 145.47 +2.903(Trichome density) -0.081(Protein content) -0.0193(TSS) -0.192(phenol content) +2.774(FAA) -11.365(reducing sugar)	0.422
Percentage Nymphal Mortality	y = 30.574 +3.427(Trichome density) -0.022(Protein) -1.210(TSS) -0.120(Phenols) -8.209(FAA) +15.023(Reducing sugar)	0.593
Adult longevity	y = -7.402 -10.941(Trichome density) +0.342(Protein content) +3.244(TSS) +0.241(Phenol content) +12.787(FAA) +5.689(Reducing sugars)	0.738
Fecundity	y = 0.878 -0.423(Trichome density) +0.010(Protein content) +0.075(TSS) +0.010(Phenol content) +0.170(FAA) +0.549(Reducing sugars)	0.803
Total life cycle	y = 138.077 -8.038(Trichome density) +0.261(Protein content) +0.305(TSS) +0.049(Phenol content) +15.562(FAA) -5.681(Reducing sugar)	0.710

at 0.01), phenol content (r = -0.479, at 0.05) and total reducing sugar content (r = -0.563, at 0.01). Though total soluble sugar content showed a positive correlation (r = 0.128) with fecundity, it was not significant. The corresponding regression model developed was

y = 0.878 -0.423(Trichome density) +0.010(Protein content) +0.075(TSS) +0.010(Phenol content) +0.170(FAA) +0.549(Reducing sugars) (R^2 = 0.803).

According to the regression equation, influence of trichome density, phenols, FAA, reducing sugars and protein content of host plants on fecundity is up to 80 per cent (R^2 = 0.803).

4.4.5 Total life span

Total life span of *A. craccivora* was positively correlated with free amino acids content (r = 0.757, at 0.01).Total life span was negatively correlated with trichome density (r = -0.762, at 0.01), total phenol content (r = -0.522, at 0.01) and reducing sugar content (r = -0.559, at 0.01).Whereas total soluble sugar content and total protein content of the host plants were also positively correlated (r = 0.161 and 0.360) with total life span of the aphid but were not significant.

This can be explained by the linear regression model

y = 138.077 -8.038(Trichome density) +0.261(Protein content) +0.305(TSS) +0.049(Phenol content) +15.562(FAA) -5.681(Reducing sugar) (R^2 = 0.710).

According to the regression equation, influence of trichome density, phenols, FAA and reducing sugars of host plants on total life cycle was up to 71 per cent (R^2 = 0.710).

4.5 OVERALL INFLUENCE OF BIOPHYSICAL AND BIOCHEMICAL CONSTITUENTS ON APHID PERFORMANCE

4.5.1 Trichomes

From the above results, it could be concluded that trichomes present on different host plants had a significant negative correlation with adult longevity, fecundity and total life cycle.

It has been an established fact that pubescence or presence of trichomes confers plant resistance to many insects including sucking insects. Our present results were in accordance with finding of Kennedy *et al.* (1978), who reported that, while working on muskmelon that pubsecnece had a negative effect on aphids. Joseph and Peter (2007) reported that in certain cowpea aphid resistance lines, presence of dense pubescence on shoot tips have conferred an antixenosis resistance to aphids by means of hindering in movement and settling of aphids.

In our study, trichomes had a negative correlation with insect biological parameters such as adult longevity, fecundity and total life span; also trichomes had a positive correlation with per cent nymphal mortality, which could be due to the fact that presence of trichomes on plant surfaces hinders the movement of aphids as well as their feeding mechanism which might have contributed to the finding of the present investigations.

4.5.2 Proteins

From our above results it was clear that protein had a significant negative impact on total nymphal duration of *A. craccivora* but also had positive correlation with adult longevity and fecundity, which gives an indication that high amount of protein, could lead to susceptible reaction in plants to insect pest. Our results were supported by Niraz *et al.* (1985) who reported a direct relationship between soluble proteins and aphid infestation in wheat crop. Narang *et al.* (1997) also reported that susceptibility of barley to corn leaf aphid *Rhopalosiphum maidis* (Fitch.) was favoured by high amount of soluble proteins, which were in accordance with our results. Mohamed and Simam (2001) while working field resistance of broad bean varieties to *A. craccivora* reported a possible positive correlation between high nitrogen and protein content in field bean to aphid infestation. Similar reports were documented by Joseh and Peter (2007).

4.5.3 Phenols

The present investigations revealed that phenol content of host plants were significantly negatively correlated with aphid's biological parameters such as total nymphal duration, adult longevity, fecundity and total life cycle and phenols also had a significant positive correlation with nymphal mortality.

Phenols are plant secondary metabolites that were evolved to deter the herbivores feeding on them. Negative effects of phenols on insect's performance, which was observed in the present investigations (Table 4.4), have been reported earlier by several workers. Leszczynski *et al.* (1989) reported that the total phenol content in winter wheat was negatively correlated (r = -0.946) with the intrinsic growth rate (r_m) of grain aphid *Sitobion avenae* (F.) conferring resistance to the aphid. Du *et al.* (2004) reported that aphid *A. gossypii* feeding on M9101 (high gossypol cultivar) displayed significantly shorter adult longevity and lower fecundity than aphids fed on ZMS13 and HZ401 (having low gossypol content). Balakrishnan (2006) reported total phenol, gossypol and tannin contents in different plant parts (leaves, squares and bolls) of different cotton varieties and hybrid had showed significant negative relationship with the incidence of leafhoppers, aphids, whiteflies and thrips. Macfoy and Dabrowski (2009) reported that correlations of total phenols and total flavonoids of some *A. craccivora* resistant lines of cowpea with resistance to the same pest.

4.5.4 Free Amino Acids

In our present investigation, free amino acids had a high degree (significance at 0.01 level) of positive correlation with aphid's performance measured in terms of their biological parameters such as adult longevity, fecundity and total life span.

Several workers have reported a positive correlation between free amino acids and insect's performances particularly sap feeding insects such as aphids. It has been well documented that principal carbon and nitrogen sources utilised by most aphids are sugars and amino acids (Dadd, 1985). Amino acids are generally considered as one of major class of nutrients that determine population increase of sap sucking insects such as aphid (Brodbeck and Strong, 1987).

Some of results of earlier workers, which are in accordance with the present investigations, are presented below.

Srivastava and Auclair (1974) reported that the presence of amino acids increased the acceptability of diets of the pea aphid, *Acyrthosiphon pisum* to a great extent. A positive correlation between total free amino acids in leaves of barley and corn leaf aphid population was reported by Narang *et al.* (1997). Chen *et al.* (1997) reported that two isogenic aphid (*A. gossypii*) resistant melon (*Cucumis melo* L.) lines were containing a low total amount of free amino acids. Karley *et al.* (2002) mentioned that 'pre-tuber-filling stage' of potato plants *Solanum tuberosum* were susceptible to aphids *Myzus persicae* and *Macrosiphum euphorbiae*, having high free amino acid level. High level of amino acids were observed in susceptible lines of soybean to aphid (*A. glycines*) whereas low level of the same was detected in aphid resistant soybean lines as reported by Mariana *et al.* (2010).

4.5.5 Reducing Sugars

Reducing sugars were negatively correlated with nymphal durations, fecundity, adult longevity and total life span, in our present investigations. Similar types of observations were presented by Joseph and Peter (2007) who reported that the *A. craccivora* resistant lines of cowpea had more reducing sugars (1.12-3.80 mg/g) but less non reducing sugars and total sugars. Masood (2014) also reported a negative correlation of glucose content (r = -0.760) (reducing sugar) of canola to aphids (*Myzus persicae*).

4.6 BIOLOGY OF LADY BIRD BEETLE (*C. SEXMACULATA*) FEEDING ON APHIDS REARED ON DIFFERENT HOST PLANTS

Biology of zigzag spotted lady bird beetle (*C. sexmaculata*) including larval developmental periods, pupal periods and adult longevity are presented in the tables 4.6a and 4.6b.

4.6.1 Egg stage

The adult female lady bird beetle, laid eggs in clusters on both the surfaces of cowpea leaf twigs, inner side of the lids and on the side wall of the plastic jar while maintaining the nucleus culture of lady bird beetles in the laboratory.

Table 4.6a Larval developmental periods (in days) of Lady bird beetle (*C. sexmaculata* Fab.) feeding on aphids reared on different host plants.

Host plants of aphids	Egg±S.D.	First instar ± S.D.	Second instar±S.D.	Third instar±S.D.	Fourth instar±S.D.	Total larval duration±S.D.	% Larval mortality±S.D.
Cowpea	2.25^{a}±0.86	1.62^{a}±0.25	1.12^{a}±0.25	1.37^{a}±0.47	2.62^{ab}±0.62	6.75^{ab}±1.04	0.00^{a}±0.00 (0.00)
Groundnut	2.50^{a}±0.70	1.75^{a}±0.28	1.37^{a}±0.47	2.00^{ab}±0.40	3.12^{b}±0.47	8.25^{c}±0.28	0.00^{a}±0.00 (0.00)
Cotton	2.25^{a}±0.64	1.75^{a}±0.28	1.12^{a}±0.25	1.25^{a}±0.70	2.37^{ab}±0.62	6.50^{a}±0.70	25.00^{a}±50.00 (22.50)
Sunflower	2.50^{a}±0.70	1.75^{a}±0.50	1.25^{a}±0.28	1.37^{a}±0.25	3.12^{b}±0.47	7.50^{abc}±0.40	25.00^{a}±50.00 (22.50)
Greengram	2.37^{a}±0.62	1.87^{a}±0.25	1.62^{a}±0.47	1.87^{ab}±0.62	2.12^{a}±0.25	7.50^{abc}±0.91	0.00^{a}±0.00 (0.00)
Blackgram	2.25^{a}±0.64	1.87^{a}±0.25	1.37^{a}±0.47	2.25^{b}±0.86	2.37^{ab}±0.47	7.87^{bc}±0.94	0.00^{a}±0.00 (0.00)
Grand Mean±S.E.	2.35±0.12	1.77±0.06	1.31±0.07	1.68±0.12	2.62±0.12	7.39±0.18	8.33±28.80 (7.50)

Values followed by same letter are not significantly different at 0.05 level as per DMRT
Values in the parenthesis are angular transformed values

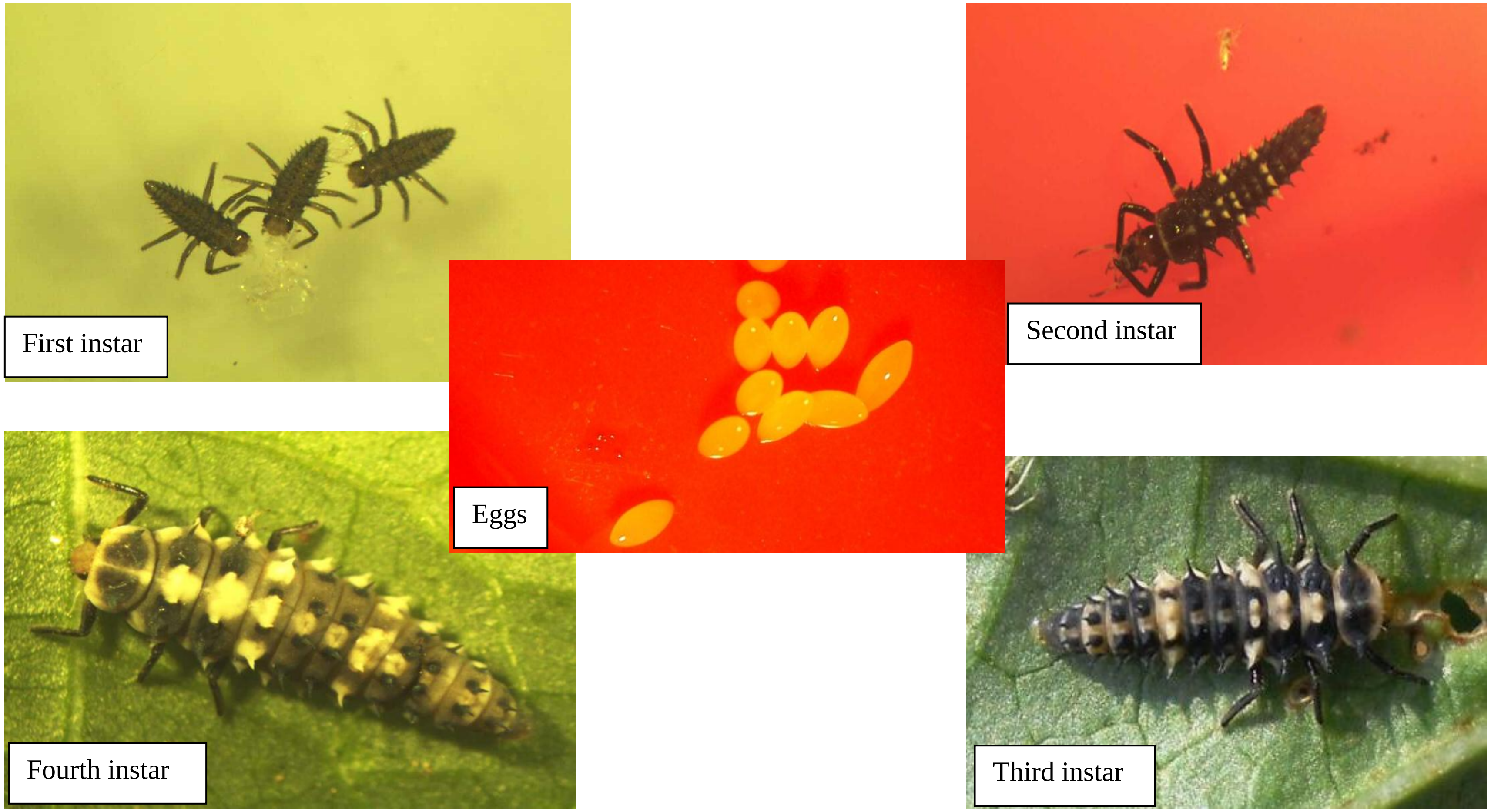


Plate 10. Eggs and different instars in grub stage of *C. sexmaculata*

Table 4.6b Pupal periods and Adult longevity (in days) of Lady bird beetle (*C. sexmaculata* Fab.) feeding on aphids reared on different host plants.

Host plants of aphids	Pre-pupal stage±S.D.	Pupal stage±S.D.	Adult Male longevity±S.D.	Adult Female longevity±S.D.	Total life span ±S.D.
Cowpea	1.00^{a}±0.40	2.87^{a}±0.47	14.00^{d}±0.70	17.00^{b}±0.70	26.12^{a}±1.65
Groundnut	0.87^{a}±0.47	2.87^{a}±0.25	13.00^{bcd}±0.70	17.75^{b}±1.06	27.87^{a}±1.65
Cotton	1.08^{a}±0.62	3.00^{a}±0.50	11.75^{ab}±0.25	14.00^{a}±0.70	19.56^{a}±8.86
Sunflower	0.91^{a}±0.52	3.16^{a}±0.57	11.00^{a}±0.50	14.25^{a}±0.35	20.68^{a}±8.56
Greengram	0.87^{a}±0.47	2.75^{a}±0.28	13.16^{cd}±0.47	16.33^{b}±1.04	26.75^{a}±1.32
Blackgram	1.12^{a}±0.47	2.87^{a}±0.25	12.16^{abc}±0.47	16.50^{b}±1.00	27.37^{a}±1.88
Grand Mean±S.E.	0.97±0.09	2.90±0.07	12.78±0.89	15.89±1.37	24.56±1.15

Values followed by same letter are not significantly different at 0.05 level as per DMRT

Freshly laid eggs were cigar shaped, yellow in colour with smooth chorion, but without any reticulations and were laid in vertical position. The eggs turned completely black before hatching. At the time of eclosion, the chorion cracked irregularly and grub wriggled out from the egg.

4.6.2 Grub

During the present study, four larval instars were observed with three moults (Plate 10).

No significant differences were observed in egg incubation, duration of first and second instar grub of lady bird beetle, when they were fed with aphids reared on different host plants (Table 4.6a).

4.6.2.1 First instar

Freshly emerged grub was dark grey in colour with shining dark head capsule and legs. The head was broadly rounded anteriorly and jointed with the thorax. The legs were relatively long and articulated with oval shaped body.

4.6.2.2 Second instar

second instar grub was shining black in colour with yellow colour head capsule and black legs. Development of white colour petches was observed on meso and meta thotax and also on fourth and six abdominal segments.

4.6.2.3 Third instar

Freshly moulted third instar grub was dull black in colour with yellow head capsule. The colour pattern was more intensified with additional development of white spots on mid dorsal line of other segments except prothorax. Duration of third instar grub was longest when fed with aphids reared on blackram (2.25±0.86 days) followed by groundnut (2.00±0.40 days), greengram (1.87±0.62 days). Shortest duration was observed when grubs were fed with aphids reared on cotton (1.25±0.70 days) followed by sunflower and cowpea (1.37±0.47 days).

4.6.2.4 Fourth instar

Fourth instar grub was deep black in colour before pupation. It developed additional rectangular dark grey spots in a continuous series mid-dorsally on abdominal segments, whereas spots on the fourth abdominal segments were white. The duration of fourth instar grub was longest when fed with aphids reared on groundnut and sunflower (both 3.12±0.47 days) followed by cowpea (2.62±0.62 days), cotton and blackgram (both 2.37±0.62 days) (not significantly different). The duration of fourth instar grub was shortest when fed with aphids reared on greengram (2.12±0.25 days) (on par with cowpea, cotton and blackgram).

4.6.3 Total larval duration

The total larval duration of lady beetle was longest when fed with aphids reared on groundnut (8.25±0.28 days) followed by blackgram (7.87±0.94 days). The duration was least when fed with aphids reared on cotton (6.50±0.70 days) followed by cowpea (6.75±1.04 days), sunflower (7.50±0.40 days) and greengram (7.50±0.91days).

4.6.4 Percentage larval mortality

Highest larval mortality was observed when the grubs were fed with aphids reared on cotton and sunflower (both 25.00±50.00%). No larval mortality was observed in other treatments (Fig. 4.3).

4.6.5 Pre-pupal stage

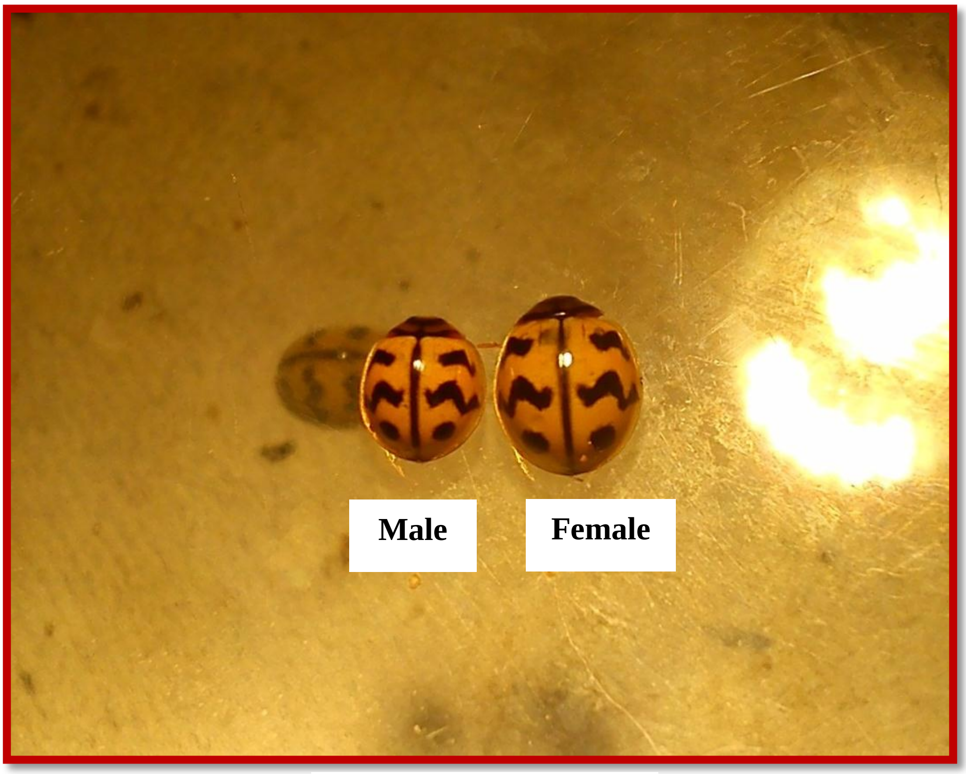
The fully grown grub stopped feeding and became sluggish and swollen before pupation (Plate 11). During this period, the larva attached posterior abdominal segment to the walls of plastic box and pupated in short time.

4.6.6 Pupal stage

Fully formed pupa was yellow in colour with black eyes and five pairs of black spots on the dorsal side that were established symmetrically on the segments.

c. Pre-pupal stage

b. Pupal stage



a. Adult stage

Plate 11. Pre-pupal, pupal and adult stages of *C. sexmaculata*

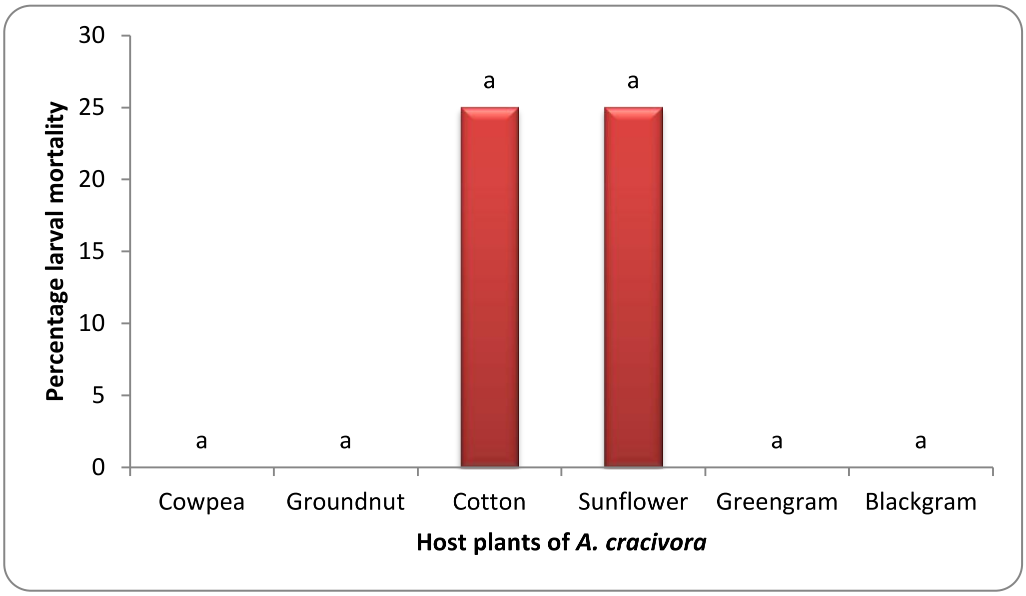


Fig. 4.3. Percentage larval mortality of *C. sexmaculata* feeding on *A. craccivora* reared on different host plants

(Bars followed by same letter are not significantly different)

The female pupa was distinctly bigger in size than the male ones (Plate 11). When disturbed, only anterior part of the pupa was able to move with its posterior end attached to the substratum.

No significant differences were observed in the pre pupal and pupal period, when the insects were fed with aphids reared on different host plants (Table 4.6b).

4.6.7 Adults

The newly emerged adults were soft, yellowish in colour without markings and remained in the pupal cases or outside. Gradually within one to two hours body hardened and turned shining yellow or warm buff with black spots which developed gradually. The elytra were yellow with two wavy markings on each elytra and pronotum was yellow with a median half-moon shaped markings connected with posterior marginal stripe (Plate 11).

4.6.7.1 Adult Male longevity

The male beetles were smaller in size, oval and convex dorsally and flat ventrally. They lived for the longer period when fed with aphids reared on cowpea (14.00±0.70 days) followed by greengram (13.16±0.47 days), groundnut (13.00±0.70 days) (both significantly different). The shortest duration of adult male was observed when they were fed with aphids reared on sunflower (11.00±0.50 days) followed by cotton (11.75±0.25 days) and blackgram (12.16±0.47 days).

4.6.7.2 Adult Female longevity

The female beetles were comparatively bigger in size, oval, convex dorsally and flat ventrally. Female adult beetles lived longer when fed with aphids reared on groundnut (17.75±1.06 days) followed by cowpea (17.00±0.70 days), blackgram (16.50±1.00 days) and greengram (16.33±1.04 days). Shortest life span of female beetles was observed when fed with aphids reared on cotton (14.00±0.70 days) and sunflower (14.25±0.35 days).

4.6.8 Total life span

The total life span of lady beetles were longest when fed to aphids reared on groundnut (27.87±1.65 days) followed by blackgram (27.37±1.88 days), greengram (26.75±1.32 days) and cowpea (26.12±1.65 days). The shortest duration of female beetles were observed when reared on cotton (19.56±8.86days) and sunflower (20.68±8.56 days). The average duration of female beetles were 24.56±1.15 days.

The egg incubation period in the present investigation varied from 2.25 days to 2.50 days which were in accordance with Subramanyam (1923), Bagal and Trehan (1945), Selhime (1955), Trehan and Malhotra (1959) and Patel (1989), who reported that the egg incubation period of *C. sexmaculata* ranged between 2.0 to 5.0 days. Suja and Beevi (2007) reported that the egg stage of *C. sexmaculata* was 2.10 days when fed on *A. craccivora.*

The morphological observations of the grubs, pupae and adults reported here in the study were similar to observations made by Zala (1995), Patel (1989) and Tank and Korat (2007).

Earlier reports on tri-trophic interaction between host plants, aphids (*A. craccivora*) and lady bird beetle (*C. sexmaculata*) were scanty and hence durations of different life stages of the lady bird beetle fed with aphids reared on different host plants, were discussed and correlated with related reports.

Duration of third instar grub varied from 1.25 days to 2.25 days, when fed with aphids reared on different host plants (Table 4.6a). Similar larval duration of third instar grubs of *C. sexmaculala* were reported by Veeravel and Baskaran (1996) who mentioned the duration of third larval instar as 2.86, 1.96, 1.50 and 1.60 days respectively at different temperatures like 18°C, 24°C, 30°C and 36°C. According Rai *et al.* (2003) and Tank and Korat (2007), the third instar grub lasted for 1.48±0.11 days and 1.88±0.53 days.

Duration of fourth instar grub varied from 2.12 days to 3.12 days, when fed with aphids reared on different host plants (Table 4.6a). Similar fourth instar larval duration were given by Veeravel and Baskaran (1996) who reported that the duration of fourth instar was 2.60, 1.86, 1.51 and 1.40 days at 18°C, 24°C, 30°C and 36°C respectively. According to Zala (1995) the duration of fourth instar grub was 2.87 days. Suja and Beevi (2007) reported that the duration of fourth instar of *C. sexmaculata* as 3.80 days. Kumar *et al.* (2013) reported duration of fourth instar grub of *C. sexmaculata* to be from three to five days with an average of 4.00±0.58 days.

Total larval duration of *C. sexmaculata* varied from 6.50 days to 8.25 days, when fed with aphids reared on different host plants (Table 4.6a). Similar larval durations were reported by Tank and Korat (2007) who reported that the larval duration of *C. sexmaculata* ranged between five to ten days. Ali *et al.* (2012) reported that the larval duration was 7.70 days at 28±1°C.

The longevity of male beetle varied from 11.00 to 14. 00 days, when fed with aphids reared on different host plants (Table 4.6b). Our above results were similar to the findings of Gupta (1966) who reported the duration of male beetle longevity as 15.0 days. Zala (1995) reported the adult longevity of male beetles as 16.2 days. Tank and Korat (2007) reported that the same duration ranged from 10 to 21 days with an average of 16.09±2.54 days. According to Lalithambika (2012) the male adult longevity of *C. sexmaculata* was 14.57±0.29 days.

The longevity of female beetle varied from 14.00 days to 17.75 days, when fed with aphids reared on different host plants (Table 4.6b). Similar reports were given by Tank and Korat (2007), who reported that the longevity of adult female *C. sexmaculata* ranged from 15 to 26 days with an average of 20.23±2.80 days. Eswaramoorthy *et al.* (1998) conducted a study on the longevity of *C. sexmaculata* and stated that the adults survived for 12.7±3.1 days when fed with aphids *Melanaphis indosacchari* (Zehntner). According to Lalithambika (2012) the female adult longevity of *C. sexmaculata* was 17.71±0.42 days.

Table 4.7a. Feeding potentiality of coccinellid beetle (*C. sexmaculata* Fab.) grubs feeding on aphids reared on different host plants.

Host plants	First instar±S.D.	Second instar±S.D.	Third instar±S.D.	Fourth instar±S.D.	Total larval duration±S.D.
Cowpea	11.00^{ab}±2.44	11.25^{a}±1.25	44.50^{ab}±5.19	130.75^{b}±14.43	197.50^{b}±11.93
Groundnut	17.50^{c}±1.91	22.25^{b}±5.56	39.25^{ab}±6.70	150.25^{b}±13.43	229.25^{b}±12.99
Cotton	8.50^{a}±2.88	10.75^{a}±2.62	31.25^{a}±7.93	35.25^{a}±24.38	85.75^{a}±34.15
Sunflower	9.75^{ab}±2.21	11.00^{a}±2.82	35.25^{ab}±1.70	53.25^{a}±13.96	109.25^{a}±10.71
Greengram	13.75^{bc}±3.09	15.25^{a}±4.34	47.25^{b}±17.25	135.00^{b}±36.36	214.25^{b}±46.77
Blackgram	12.50^{ab}±5.06	16.00^{a}±3.16	48.75^{b}±1.70	137.75^{b}±14.24	212.50^{b}±19.05
Grand Mean±S.E.	12.16±0.83	14.41±1.06	41.04±2.03	107.04±10.15	174.75±12.56

Values followed by same letter are not significantly different at 0.05% as per DMRT

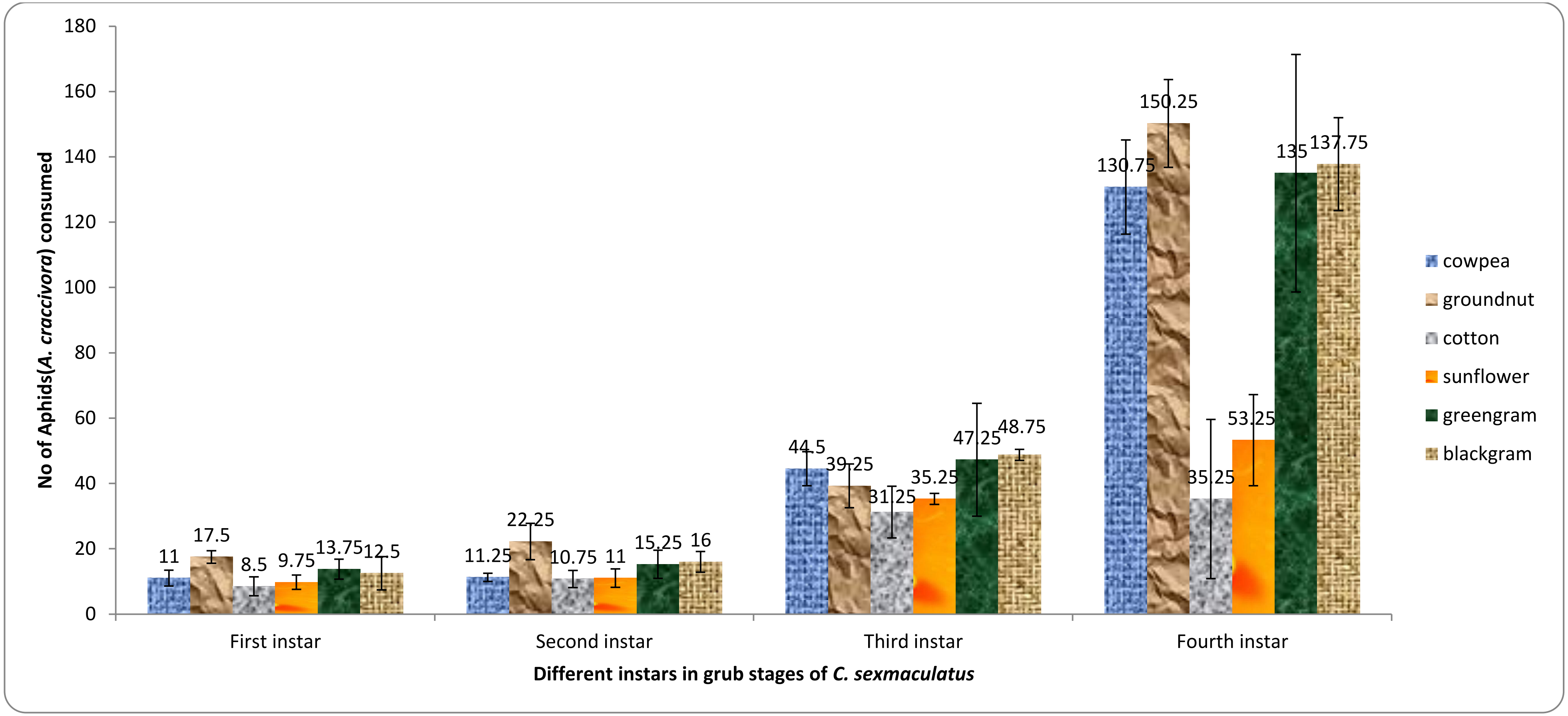


Fig. 4.4. Feeding potentiality of different larval instars of *C. sexmaculatus* on aphids (*A. craccivora*) reared on different host plants

4.7 FEEDING POTENTIALITY OF COCCINELLID BEETLE (*C. SEXMACULATA* FAB.) GRUBS FEEDING ON APHIDS REARED ON DIFFERENT HOST PLANTS

Feeding potential of the coccinellid beetle was expressed as number of aphids consumed per respective stage of the lady bird beetle and the findings were presented in Table 4.7a, 4.7b and Fig. 4.4.

4.7.1 First instar

The feeding potential of first instar grubs of lady bird beetle, was highest when offered with aphids reared on groundnut (17.50±1.91) followed by greengram (13.75±3.09). The feeding potential was least, when the first instar grubs of lady bird beetle were offered with aphids reared on cotton (8.50±2.88 aphids) followed by sunflower (9.75±2.21 aphids), cowpea (11.00±2.44 aphids) and blackgram (12.50±5.06 aphids).

4.7.2 Second instar

The feeding potential oftar second instar grubs of lady bird beetle, was highest when offered with aphids reared on groundnut (22.25±5.56 aphids) (significantly different from others) followed by blackgram (16.00±3.16 aphids), greengram (15.25±4.34 aphids), cowpea (11.25±1.25 aphids), sunflower (11.00±2.82 aphids) and cotton (10.75±2.62 aphids) (on par with each other).

4.7.3 Third instar

The feeding potential of third instar grubs of lady bird beetle, was highest when offered with aphids reared on blackgram (48.75±1.70 aphids) followed by greengram (47.25±17.25 aphids), cowpea (44.50±5.19 aphids) and groundnut (39.25±6.70 aphids) (not significantly different). The feeding potential was least, when the third instar grubs of lady bird beetle were offered with aphids reared on cotton (31.25±7.93 aphids) and sunflower (35.25±1.70 aphids).

4.7.4 Fourth instar

During this instar, highest no of aphids (highest feeding potential) were consumed when the grubs of lady bird beetles were offered with aphids reared on groundnut (150.25±13.43 aphids) followed by blackgram (137.75±14.24 aphids), greengram (135.00±36.36 aphids) and cowpea (130.75±14.43 aphids). Least number of aphids (lowest feeding potential) was observed when the grubs were offered with aphids reared on cotton (35.25±24.38 aphids) followed by sunflower (53.25±13.96 aphids).

4.7.5 Total larval duration

During the entire larval duration of lady beetle, highest number of aphids were consumed, when they were reared on groundnut (229.25±12.99 aphids) followed by greengram (214.25±46.77 aphids), blackgram (212.50±19.05 aphids), cowpea (197.50±11.93 aphids) (significantly different). Least number of aphids were consumed, when they were reared on cotton (85.75±34.15 aphids) followed by sunflower (109.25±10.71 aphids) (significantly different).

4.7.6 Predatory capacity of adult male beetle

The predatory capacity of adult male beetle was highest when the adults were offered with aphids reared on groundnut (588.5±27.57 aphids) (significantly different), greengram (539.23±32.13 aphids), cowpea (519.5±14.84 aphids) and blackgram (509.00±37.87 aphids) (not significantly different). Least amount of aphids were consumed by the adult male beetle when they were offered with aphids reared on cotton (425.00±17.89 aphids) and sunflower (469.11±28.46 aphids) (Fig. 4.5).

4.7.7 Predatory capacity of adult female beetle

The adult female beetle consumed highest numbers of aphids, when they were offered with aphids reared on groundnut (903.00±39.59 aphids) (significantly different) followed by blackgram (797.33±20.40 aphids),

Table 4.7b. Feeding potentiality of coccinellid beetle (*C. sexmaculata* Fab.) adults feeding on aphids reared on different host plants.

Host plants	Adult male consumption±S.D.	Adult female consumption±S.D.	Gross consumption ± S.D.
Cowpea	519.5[b]±14.84	680.00[b]±29.69	797.25[b]±88.85
Groundnut	588.5[c]±27.57	903.00[c]±39.59	975.00[b]±191.38
Cotton	425.00[a]±17.89	528.00[a]±12.72	456.00[a]±284.77
Sunflower	469.11[a]±28.46	547.00[a]±9.89	500.00[a]±265.32
Greengram	539.23[b]±32.13	757.66[d]±25.02	917.25[b]±79.83
Blackgram	509.00[b]±37.87	797.33[d]±20.40	937.75[b]±158.17
Grand Mean±S.E.	519.75±20.03	712.92±35.55	763.87±56.10

Values followed by same letter are not significantly different at 0.05 level as per DMRT

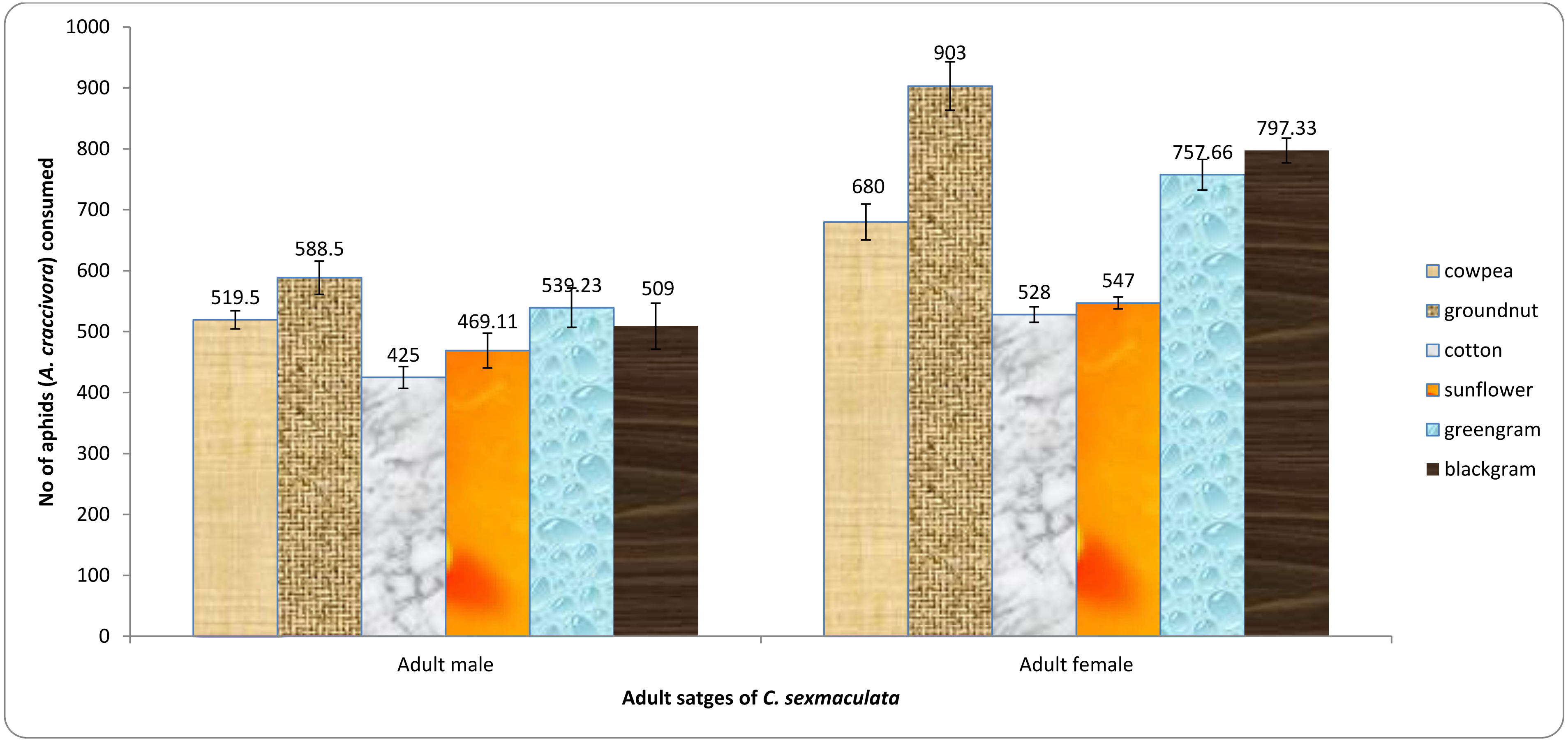


Fig. 4.5. Feeding potentiality of adult stages of *C. sexmaculatus* on aphids (*A. craccivora*) reared on different host plants

greengram (757.66±25.02 aphids), cowpea (680.00±29.69 aphids) (significantly different). The adult female beetle consumed lowest number of aphids, when they were offered with aphids reared on cotton (528.00±12.72 aphids) followed by Sunflower (547.00±9.89 aphids).

4.7.8 Gross consumption in entire life span

During the entire life span of the beetle *C. sexmaculata* (including both larval and adult stages) highest number of aphids were consumed when the predator was offered with aphids reared on groundnut (975.00±191.38 aphids) followed by blackgram (937.75±158.17 aphids), greengram (917.25±79.83 aphids), cowpea (797.25±88.85 aphids). Least numbers of aphids were consumed, when they were reared on cotton (456.00±284.77 aphids) and sunflower (500.00±265.32 aphids) (table 4.7b).

Our present studies have indicated that the first instar grub of *C. sexmaculata* had feeding potential ranging from 8. 50 to 13.75 aphids reared on different host plants (Table 4.7a). The mean number of aphids consumed during the first instar grub of lady beetle was 12.16±0.83 aphids. Our results were similar to Kumar (1992) who reported that the first instar grub of *Menochilus sexmaculata* consumed 16.0 aphids during its grub period.

Second instar grub of *C. sexmaculata* had a feeding potential ranging from 10.75 to 16.00 aphids reared on different host plants (Table 4.7a). Overall the mean aphids consumed by the second instar grub were 14.41±1.06 aphids. These results were in line with Patel and Vyas (1984) who reported predatory capacity of *M. sexmaculata* as 16.28 aphids during the entire grub stage of second instar.

The feeding potential of third instar grub of *C. sexmaculata* varied from 31.25 to 48.75 aphids, reared on different host plants. During third instar the mean number of aphids consumed by grub was 41.04±2.03 (Table 4.7a). Seshadri (1970), reported the feeding potentiality of third instar grub of *C. sexmaculata* as 40.21 aphids (*A. craccivora*). Verma *et al.* (1983) reported that the third instar grub of *C. sexmaculata* fed on 32.20 aphids, throughout its grub stage. Our present results were in accordance with above mentioned reports.

The feeding potential of fourth instar grub of *C. sexmaculata* varied from 35.25 to 150.25 aphids, reared on different host plants (Table 4.7a). Similar observations were reported by Mani *et al.* (2005) who found that fourth instar grub of *C. sexmaculata* could fed up to 141.5 aphids during its grub period.

During the entire grub period of *C. sexmaculata*, the feeding potential varied from 85.75 to 229.25 aphids that were reared on different host plants. The mean number of aphids consumed during the entire grub period was 174.75±12.56 aphids. These results were strongly supported by the previous findings of Ray (1967), Bose and Ray (1967), Das (1991) and Singh *et al.* (2009). Ray (1967) reported the grub of *C. sexmaculata* could feed up to 165.0 to 203.0 aphids. Bose and Ray (1967) reported the larvae of *C. sexmaculata* could consume 143-189 individuals of aphids. Das (1991) reported that one larva of *M. sexmaculatus* consumed 270.0 to 367.0 *A. craccivora* prior to pupation. Singh *et al*. (2009) reported that *M. sexmaculatus* consumed 62.00±0.78 to 211.40±2.68 aphids.

The predatory capacity of adult male beetle in the present investigations ranged from 425 to 588.5 aphids that were reared on different host plants (Table 4.7b). During the entire adult stage a single male beetle consumed as an average of 519.75±20.03 aphids. Our results were supported by the findings of Kumar *et al.* (2013), who reported that a male beetle (*C. sexmaculata*) consumed 510.33±9.82 *A. craccivora* (ranged 500-521 aphids).

The predatory capacity of adult female beetle ranged from 528.00 to 903.00 aphids that were reared on different host plants. The mean number of aphids consumed by the adult female was712.92±35.55 aphids (Table 4.7b). Kumar *et al.* (2013) reported that a female beetle of *C. sexmaculata* consumed 718.00±17.21 *A. craccivora* (ranged 710-725 aphids), which was in accordance with our results. The feeding potential of the beetle (including both larval and adult stages) ranged from 456.00 to 975.00 aphids that were reared on different

Table 4.8 Daily average Feeding of coccinellid beetle (*C. sexmaculata* Fab.) feeding on aphids reared on different host plants.

Host plants	First instar±S.D.	Second instar±S.D.	Third instar±S.D.	Fourth instar±S.D.	Larval duration±S.D.	Daily consumption (Male)±S.D.	Daily consumption (Female)±S.D.
Cowpea	6.83^{ab}±1.67	10.33^{a}±2.36	35.83^{b}±13.61	51.17^{b}±8.85	28.40^{b}±4.62	37.13^{a}±0.81	40.07^{ab}±3.41
Groundnut	10.08^{b}±0.79	18.42^{b}±8.60	20.54^{a}±7.16	49.50^{b}±12.38	25.26^{b}±3.50	46.84^{c}±2.55	54.09^{c}±5.79
Cotton	4.83^{a}±1.37	9.75^{a}±2.75	26.25^{ab}±10.61	17.10^{a}±15.36	15.63^{a}±12.77	35.88^{a}±0.65	37.79^{a}±2.82
Sunflower	6.38^{a}±3.84	9.33^{a}±3.97	26.25^{ab}±4.53	17.04^{a}±3.22	10.32^{a}±1.76	41.22^{b}±0.61	38.39^{a}±0.26
Greengram	7.38^{ab}±1.49	9.71^{a}±2.58	25.08^{ab}±1.35	63.90^{b}±18.42	28.06^{b}±5.13	40.49^{b}±0.53	46.49^{bc}±2.82
Blackgram	6.63^{a}±2.29	12.17^{ab}±2.47	23.86^{ab}±7.71	59.26^{b}±9.41	26.62^{b}±4.60	41.09^{b}±0.51	48.47^{c}±3.81
Grand Mean±S.E.	7.02±0.50	11.61±1.03	26.30±1.81	42.99±4.53	22.38±1.84	40.49±0.92	44.68±1.73

Values followed by same letter are not significantly different at 0.05 level as per DMRT

host plants. The mean aphids consumed in entire life span of a lady beetle was 763.87±56.10 aphids (Table 4.7 b). These results were supported by the previous findings of Verma *et al.* (1983) and Singh *et al.* (2009).

4.7.9 Daily average feeding of coccinellid beetle (*C. sexmaculata* Fab.) feeding on aphids reared on different host plants

Daily average feeding potential of lady beetle is presented in Table 4.8.

4.7.9.1 First instar

The daily average feeding of first instar grub of *C. sexmaculata* was about 10.08±0.79 aphids/day, when aphids were reared on groundnut (highest) followed by greengram (7.38±1.49 aphids/day), cowpea (6.83±1.67 aphids/day), blackgram (6.63±2.29 aphids/day). Least daily average feeding potential was noticed, when aphids were reared on cotton (4.83±1.37 aphids/day) and sunflower (6.38±3.84 aphids/day).

4.7.9.2 Second instar

During second instar the daily average feeding was least when aphids were reared on sunflower (9.33±3.97 aphids/day) followed by greengram (9.71±2.58 aphids/day), cotton (9.75±2.75 aphids/day), cowpea (10.33±2.36 aphids/day), blackgram (12.17±2.47 aphids/day). Highest feeding potentiality was noticed when aphids were reared on groundnut (18.42±8.60 aphids/day) (on par with that of blackgram).

4.7.9.3 Third instar

During third instar highest daily average feeding was noticed when aphids were reared on cowpea (35.83±13.61 aphids/day) followed by sunflower (26.25±4.53 aphids/day) cotton (26.25±10.61 aphids/day), greengram (25.08±1.35 aphids/day), blackgram (23.86±7.71 aphids/day). Highest daily average feeding was noticed when aphids were reared on groundnut (20.54±7.16 aphids/day) (on par with cotton, sunflower, greengram and blackgram).

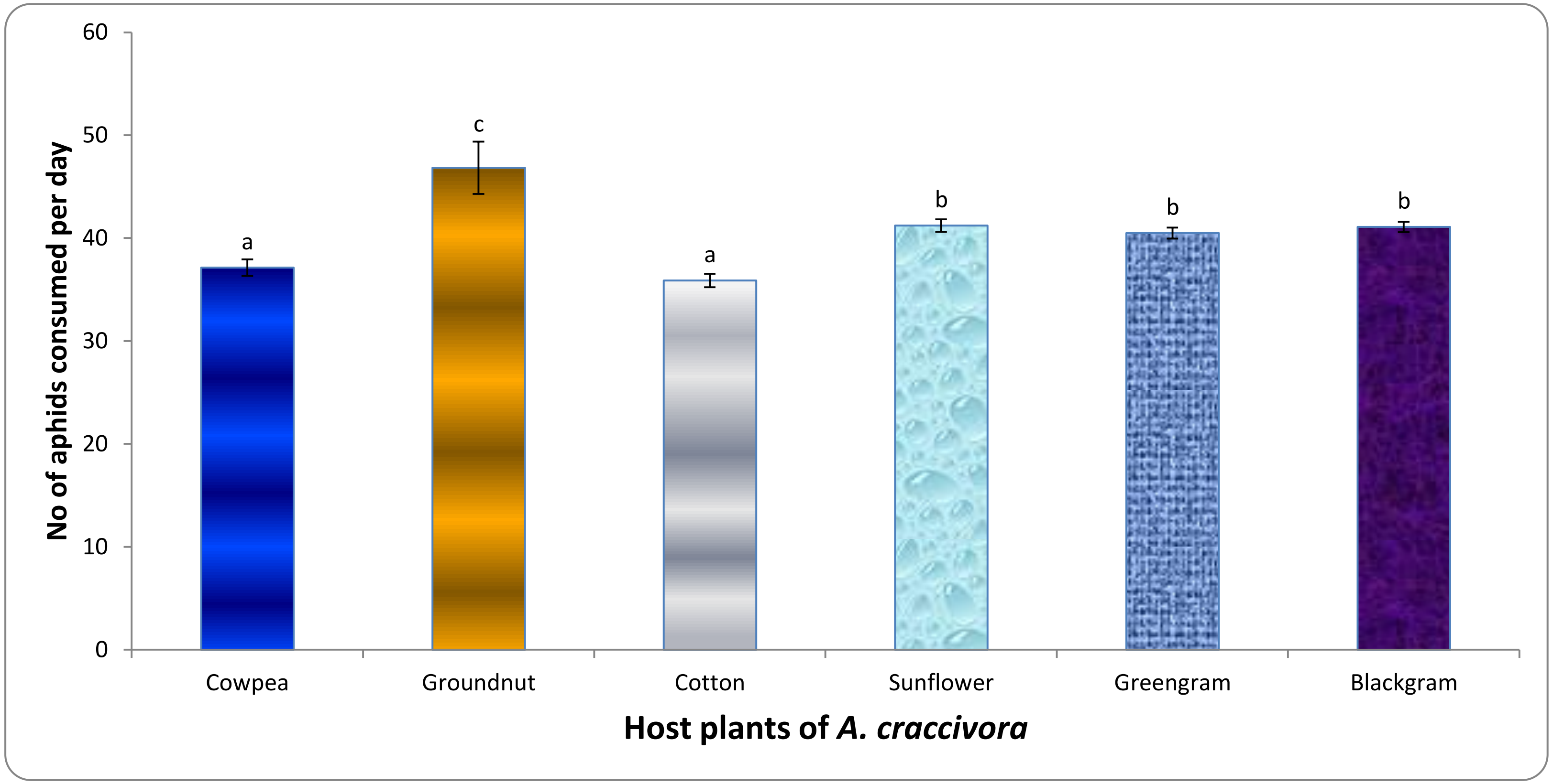


Fig. 4.6. Daily average feeding potentiality of adult male *C. sexmaculata* on *A. craccivora* reared on different host plants
(Bars followed by same letter are not significantly different)

4.7.9.4 Fourth instar

During fourth instar, highest daily average feeding potential was noticed when aphids were reared on greengram (63.90±18.42 aphids/day) followed by blackgram (59.26±9.41aphids/day), cowpea (51.17±8.85 aphids/day) and groundnut (49.50±12.38 aphids/day). Lowest daily average feeding potential was noticed when aphids were reared on sunflower (17.04±3.22 aphids/day) followed by cotton (17.10±15.36 aphids/day).

4.7.9.5 Larval duration

During the total grub period, highest daily average feeding potential was noticed, when aphids were reared on cowpea (28.40±4.62 aphids/day) followed by greengram (28.06±5.13 aphids/day), blackgram (26.62±4.60 aphids/day), groundnut (25.26±3.50 aphids/day) (not significantly different). Least daily average feeding potentiality was noticed when aphids were reared on sunflower (10.32±1.76 aphids/day) followed by cotton (15.63±12.77 aphids/day).

4.7.9.6 Adult male

Highest daily average feeding potential of adult male beetle was noticed in case when aphids were reared on groundnut (46.84±2.55 aphids/day) (significantly different) followed by sunflower (41.22±0.61 aphids/day), blackgram (41.09±0.51 aphids/day) , greengram (40.49±0.53 aphids/day). Least daily average feeding potentiality was noticed when aphids were reared on cotton (35.88±0.65 aphids/day) and cowpea (37.13±0.81 aphids/day) (not significantly different) (Fig. 4.6).

4.7.7 Adult female

Highest daily average feeding potentiality of adult female beetle was noticed, when aphids were reared on groundnut (54.09±5.79 aphids/day) followed by blackgram (48.47±3.81 aphids/day), greengram (46.49±2.82

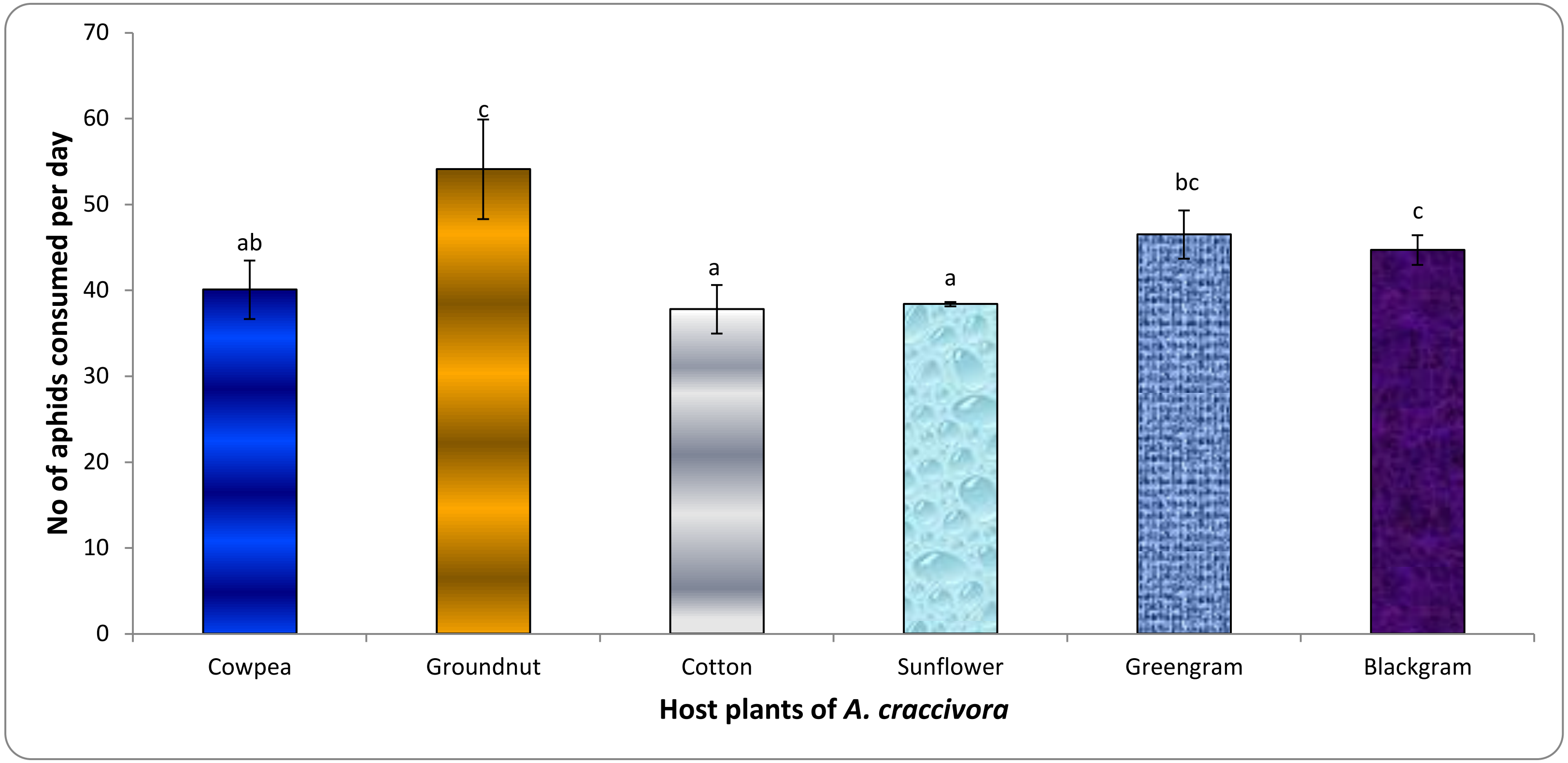


Fig. 4.7. Daily average feeding potentiality of adult female *C. sexmaculata* on *A. craccivora* reared on different host plants
(Bars followed by same letter are not significantly different)

aphids/day) (not significantly different) and cowpea (40.07±3.41 aphids/day). Least daily average feeding potentiality was noticed when aphids were reared on cotton (37.79±2.82 aphids/day) and sunflower (38.39±0.26 aphids/day) (not significantly different) (Fig. 4.7).

During the first instar, the daily average feeding potential ranged from 4.83 to 10.08 aphids per day. The mean daily average feeding potential was 7.02±0.50 aphids/day (Table 4.8). Similar types of results were reported by Patel (1989). According to whom, the first instar grub fed about 7.60 aphids/day.

During second instar, the daily average feeding potential ranged from 9.33 to 18.42 aphids per day. The mean daily average feeding potential of second instar grub was about 11.61±1.03 aphids/day. The above findings were supported by the previous findings of Patel (1989). He reported the per day feeding ability of second instar grub was 16.28 aphids.

During third instar the daily average feeding potential ranged from 20.54 to 35.83 aphids/day. The mean daily average feeding during third instar grub was about 26.30±1.81 aphids/day. Patel (1989) reported similar types of results *i.e.* feeding potential of third instar grub as 23.39 aphids/day.

During fourth instar highest daily average feeding potential ranged from 17.04 to 63.90 aphids/day. The mean daily average feeding potential for the fourth instar was 42.99±4.53 aphids/day (Table 4.8). The above findings were supported by the previous findings of Patel (1989).

The daily average feeding potential during the larval or grub stage of *C. sexmaculata* varied from 10.32 to 28. 40 aphids/day, when aphids were reared on different host plants. The daily average feeding potential of the grub stage was 40.49±0.92 aphids/day (Table 4.8). Our results were strongly supported by the previous findings of Haque and Islam (1978). According to them, *M. sexmaculatus* can feed 21.1 to 41.7 aphids (*A. craccivora*) per day. Pandi *et al.* (2013) also reported similar observations who reported that the average per day predation rate of larval *C. sexmaculata* ranged from 6.4±0.51 to 79±1.86 when fed to *A. craccivora*.

The daily average feeding potential of male beetle ranged from 35.88 to 46.84 aphids per day, when aphids were reared on different host plants. The daily average feeding potential of male beetle was 40.49±0.92 aphids/day (Table 4.8). Similar types of findings were reported by Pandi *et al.* (2013). According to them, male could feed on 35.8±2.67 of *A. craccivora* per day.

The daily average feeding potential of female beetle ranged from 37.79 to 54.09 aphids per day, when aphids were reared on different host plants. The daily average feeding potential of female beetle was 44.68±1.73 aphids/day (Table 4.8). Similar findings were reported by the following scientists. Prabhakar and Roy (2010) reported that when fed on *A. craccivora*, *C. sexmaculata* could consume about 48.0±1.20, 33.2±1.25 nymphs (by male and female respectively) and 41.3±0.72, 30±2.0 on adult aphids. Kumar *et al.* (2013) reported that the adult female beetle can consume an average of 35.93 *A.craccivora* per day. Pandi *et al.* (2013) reported that per day predation rate (number of aphids) by female beetle on *A. craccivora* was 37.2±3.32.

4.8 TRI-TROPHIC INTERACTIONS

The above results regarding biology of aphids, lady beetles, feeding potentiality of the later and the host plant characters are interpreted as a multitrophic interactions below.

4.8.1 Effect of biophysical and biochemical characters of host plants on third trophic level

While studying the biology of aphids on different host plants, we found that aphid performance on different host plants were in order of most preferred to least preferred as cowpea > groundnut > greengram > blackgram > sunflower > cotton (Table 4.1a and 4.1b).

From the morphometrical data (Table 4.2d and table 4.2e) it is clear that overall body size (both body length and width) of different instars and adults of *A. craccivora* was more, when reared on cowpea and was least, when reared on groundnut. Their ranking were (from highest body length and width to lowest) in the order of cowpea > greengram = blackgram = groundnut. On cotton and sunflower, the nymphs could not survive to reach adult stage and hence there is no data on cotton and sunflower.

From the present study on the biology of lady bird beetle, it was observed grubs of *C. sexmaculata* took more time to complete its grub life cycle, when fed with aphids reared on groundnut followed by greengram and blackgram and least grub period was observed when the grubs were fed with aphids reared on cowpea (Table 4.6a). This phenomenon was being reflected from the Morphometric data of aphid nymphs and adults from Table 4.2a to 4.2e where aphids reared on groundnut were much smaller followed by greengram and blackgram and biggest aphids were obtained when they were reared on cowpea.

It is generally believed that low nutrient status in resistant host plants can reduce the size and weight of the insects feeding on them, prolong the duration of life stages etc., and make the insect pest more vulnerable to attack by natural enemies (Dhaliwal and Dilwari, 1993). In our present study, the low nutrient status of groundnut might have contributed to smaller size of aphids feeding on them and high nutritional status of cowpea contributed in producing bigger aphids.

Subsequently because of low nutritional status of groundnut plants, aphids reared on these plants would also be low in their nutritional status and hence the both grubs and adults of *C. sexmaculata* consumed more number of aphids (Table 4.7a) and also took longer period of time (Table 4.6a) to complete their life cycle.

Contrarily, because of high nutritional status of cowpea, nymphs and adult aphids reared on cowpea were bigger (Table 4.2a to 4.2e) and because of high nutritional status of aphids reared on cowpea both grubs and adults of *C. sexmaculata* consumed fewer number of aphids (Table 4.7a) and took less time to complete their life cycle (Table 4.6a).

Similar types of findings were reported by Barkhordar *et al.* (2013). They studied the Impact of host plant resistance on the tri-trophic interactions between wheat genotypes, aphids (*Schizaphis graminum*), and coccinellid beetle, *Coccinella septempunctata*. They reported that digestibility of aphids (by beetle), *S. graminum* fed on resistant plant genotypes is higher than those fed on susceptible plants because of the lighter weights and smaller sizes of the first. This phenomenon could result in faster ingestion of *S. graminum* by *C. septempunctata* on these resistant plants.

Bottenberg *et al.* (1998) reported that the use of aphid resistant cowpea varieties combined with the presence of natural enemies can be an effective means of pest control.

In an another tri-trophic study, Murugan *et al.* (2000) reported increased reproductive period, total life span and fecundity of *A. nerii,* when reared on mature leaves of *Calotropis gigantean.* Fecundity and longevity of lady beetle *M. sexmaculatus* were high and developmental time of predator was shorter when fed to aphids reared on mature leaves. Maximum prey utilization and increased efficiency of ingested and digested food of predator was observed on mature leaves reared aphid as compare to those on young and older leaves. Similarly, Giles *et al.* (2002) reported increased survival rate, decreased developmental times and larger size of *C. septempunctata* when fed with aphid *A. pisum* reared on *Medicago sativa* (due to high fatty acids supply through aphids) as compare to the situation when aphids were reared on *Vicia faba*.

In other tri-trophic study by Down *et al.* (2003) about 10% reduction in egg viability of lady beetle *Adalia bipunctata* was reported when fed to aphids *Myzus persicae* reared on transgenic potato plants expressing the insecticidal lectin from snowdrop (Galanthus nivalis agglutinin; GNA). Jalali and Michaud (2012) reported that the aphid, *Myzus persicae* feeding on sweet pepper had better suitability for the lady beetle, *Adalia bipunctata* due to better nutritive value; whereas the same aphid feeding on tabacco was least suitable for the predator due to toxicity nature.

From studies on biophysical and biochemical constituents of host plants (Table 4.3), it was observed that both cotton and sunflower had significant numbers of trichomes and significant quantity of phenols. Both trichomes and phenols had a significant negative correlation with aphid's biological characters and positive correlation with aphid nymphal mortality (Table 4.4). It can concluded that the phenols present in cotton and sunflower contributed to their very poor host status that also led to increase in aphid nymphal mortality.

Consequently, when aphids reared on cotton and sunflower were offered to both grubs and adults of *C. sexmaculata*, the feeding potential of both grubs and adults were very less (grubs and adults consumed very few aphids reared on cotton and sunflower). The biochemical constituents (phenols) present in cotton and sunflower which contributed to aphid nymphal mortality, also affected the biology feeding potentiality of lady bird beetle (third trophic level). Around 25 per cent grub mortality was observed when grubs of lady bird beetle were offered with aphids reared on cotton and sunflower (Table 4.6a).

Hence comparatively less trichome densities, high protein, TSS and free amino acid contents in host plants affected positively to second trophic level (*A. craccivora*), but affected negatively to the biology and feeding potentiality of third trophic level (*C. sexmaculata*) and vice versa.

Chapter – V

Summary and Conclusions

Chapter V

SUMMARY AND CONCLUSIONS

Studies on the biology and morphometrics of aphid, *A. craccivora* Koch. on six different host plants *viz.*, cotton, sunflower, cowpea, groundnut, greengram and blackgram, along with their biophysical and biochemical characteristics were carried out 2014 and 2015 in Department of Entomology, S.V. Agricultural College and Regional Agricultural Research Station, Tirupati. Experiments were also carried out on tri-trophic interaction of host plants, an aphid herbivore and a natural enemy *C. sexmaculata* Fab. The summary and conclusions of the results are furnished below.

Nucleus culture of *A. craccivora* was maintained on a susceptible cowpea cultivar (CO-702). Biology studies were carried out in laboratory condition of 28±2^{o}C temperature and 75-80 per cent RH. During the biology study, it was found that total nymphal duration was shortest on cotton (92.40±9.87 h) followed by groundnut (103.20±14.08h), cowpea (104.40±8.09h), sunflower (110.40±11.02 h), blackgram (123.6±18.80 h) and greengram (124.8±10.11 h). Highest nymphal mortality was observed on cotton and sunflower (100%), followed by blackgram, greengram and groundnut (20%). No nymphal mortality was noticed on cowpea.

During post nymphal developmental periods of *A. craccivora*, longest oviposition period were noticed when aphids were reared on cowpea (188.40±28.87 h) followed by greengram (96.0±62.51 h), groundnut (85.50±11.89 h) and blackgram (75.00±63.74 h). Adult longevity of *A. craccivora* were longest on cowpea (231.60±40.41 h) followed by groundnut (100.80±54.61 h), greengram (99.60±77.36 h) and blackgram (86.40±73.27 h). Whereas, the duration of total life span was longest on cowpea (336.00±37.94 h) followed by greengram (224.40±81.98 h), blackgram (210.00±66.03 h) and groundnut (204.00±57.96 h).

A. craccivora reared on cowpea (52.00±10.92), gave birth to highest numbers of nymphs followed by groundnut (21.12±2.64), greengram (12.62±8.38) and blackgram (9.87±8.67).

Aphids reared on cowpea, had longest oviposition period, fecundity and adult longevity thus making cowpea as most preferred host for *A. craccivora* followed by groundnut, greenram, blackgram, sunflower and cotton.

Morphometrics data of *A. craccivora* indicated that during first instar there was no significant difference in body length, body width, antennal length, head capsule width, cornicle length and caudal length of aphids reared on different host plants.

Body length of second instar nymphs was longest (0.91±0.02 mm) when aphids were reared on cowpea (significantly different) followed by greengram (0.83±0.03 mm), groundnut (0.80±0.01 mm) and blackgram (0.80±0.01 mm). Body width was also highest, when aphids were reared on cowpea (0.51±0.01 mm), followed by greengram (0.45±0.01 mm), groundnut (0.44±0.00 mm) and blackgram (0.44±0.00 mm).

Body length and body width of third instar nymphs were longest (1.25± 0.12; 0.59±0.03 mm), when aphids were reared on cowpea followed by greengram (1.17±0.06 mm; 0.53±0.02 mm) (significantly different). The shortest body length and width (1.15±0.03 mm; 0.48±0.02 mm), was observed when aphids were reared on groundnut and blackgram.

Body length of fourth instar nymph was longest (1.56±0.01 mm), when aphids were reared on cowpea which was significantly different from other host plants. Shortest body length was found, when aphids were reared on groundnut (1.25±0.03 mm) followed by blackgram (1.32±0.02 mm), greengram (1.40±0.01 mm) (at par with that of blackgram). Body width was longest when aphids were reared on cowpea (0.80±0.00 mm) followed by greengram (0.72±0.01 mm) (significantly different). Shortest body width was observed when aphids were reared on groundnut (0.54±0.01 mm) followed by blackgram (0.55±0.01 mm).

Longest body length of adult was observed, when aphids were reared on cowpea (2.33±0.14 mm) (significantly different) followed by greengram (1.96±0.15 mm), blackgram (1.90±0.03 mm) and groundnut (1.82±0.04 mm). Longest body width (1.18±0.02 mm) was found, when aphids were reared on cowpea (significantly different), followed by greengram (1.08±0.06 mm), blackgram (0.95±0.07 mm) and groundnut (0.93±0.04 mm).

From the host plant constituents study it was found that cotton leaves had highest trichome density in leaves (265.9±78.97 per 0.25 cm^2) followed by sunflower (152.1±42.89), blackgram (86.7±23.65), greengram (78.8±19.43), groundnut (17.3±8.40) and cowpea (0.00±0.00). Correlation studies between aphid performance and trichome density of different host plants, revealed a negative correlation of trichome density with adult longevity, fecundity and total life span and a positive correlation between trichome density and percentage nymphal mortality of *A. craccivora*.

From plant biochemical analysis it was found that cowpea leaves contained highest protein content (335.21±29.58 mg/g) whereas, sunflower leaves contained lowest protein content (139.53±26.13 mg/g). Correlation study indicated that total protein content of host plants was significantly negatively correlated with the total nymphal duration and was significantly positively correlated with the adult longevity and fecundity of *A. craccivora*.

Total soluble sugar content was highest in cowpea leaves (13.04±1.34 mg/g) and was least in cotton leaves (5.53±0.92 mg/g). But no significant correlation was noticed between TSS content and any growth parameters of *A. craccivora*.

The phenol content of all the host plants were significantly correlated with the aphid growth parameters. Highest phenol content was noticed in cotton (260.46±31.43 mg/g) and least phenol content was noticed in cowpea (49.29±17.04 mg/g). Phenol content of host plants was negatively correlated with total nymphal duration, adult longevity, fecundity and total life span of *A.*

craccivora. Whereas, it was significantly positively correlated with percentage nymphal moratlity.

Lowest amount of total free amino acids were found in the leaves of sunflower (0.40±0.41 mg/g) and highest content of amino acids were noticed in cowpea leaves (5.68±2.26 mg/g). Total free amino acids content was significantly positively correlated with adult longevity, fecundity and total life span. Whereas it was significantly negatively correlated with percentage nymphal mortality of aphids.

Total reducing sugars were highest in sunflower leaves (3.15±0.23 mg/g) and were lowest in cowpea leaves (1.82±0.38 mg/g). Total reducing sugar content was significantly negatively correlated with adult longevity, fecundity and total life span whereas the same was significantly positively correlated with percentage nymphal mortality.

Biology and feeding potentiality study of lady bird beetle *C. sexmaculata* was carried out in laboratory providing aphids reared on six different host plants. During the life cycle of *C. sexmaculata*, egg, total four instars of grubs were noticed with pupal and adult stages.

The total larval duration of lady beetle was longest when fed on aphids reared on groundnut (8.25±0.28 days) followed by blackgram (7.87±0.94 days) (not significantly different). The same duration was least when aphids were reared on cotton (6.50±0.70 days) followed by cowpea (6.75±1.04 days), sunflower (7.50±0.40 days) and greengram (7.50±0.91days) (not significantly different).

Highest grub mortality of lady bird beetle was observed in cotton and sunflower (both 25.00±50.00%). Least percentage of mortality was observed in case of cowpea, groundnut, green gram and black gram (all 0.00±0.00%).

The pupal duration of the lady bird beetle was longest when fed on aphids reared on sunflower (3.16±0.57 days) followed by cotton (3.00±0.50 days), cowpea (2.87±0.47 days), groundnut and blackgram (2.87±0.25 days). Shortest duration of pupae was observed in case of greengram (2.75±0.28 days).

Adult male lady bird beetles, lived for the longer period when fed to aphids reared on cowpea (14.00±0.70 days) followed by greengram (13.16±0.47 days), groundnut (13.00±0.70 days). The shortest duration of adult male beetle was observed when reared on sunflower (11.00±0.50 days) followed by cotton (11.75±0.25 days) and blackgram (12.16±0.47 days).

The duration of female lady bird beetle were longest when fed on aphids reared on groundnut (17.75±1.06 days) followed by cowpea (17.00±0.70 days), blackgram (16.50±1.00 days) and greengram (16.33±1.04 days). Shortest period of female beetles were observed when fed on aphids reared on cotton (14.00±0.70 days) and sunflower (14.25±0.35 days).

The total life span of lady beetles were longer period when fed to aphids reared on groundnut (27.87±1.65 days) followed by blackgram (27.37±1.88 days), greengram (26.75±1.32 days) and cowpea (26.12±1.65 days). The shortest duration of female beetles were observed when reared on cotton (19.56±8.86days) and sunflower (20.68±8.56 days).

During the entire larval duration of lady beetle, highest no. of aphids were consumed when reared on groundnut (229.25±12.99 aphids) followed by greengram (214.25±46.77 aphids), blackgram (212.50±19.05 aphids), cowpea (197.50±11.93 aphids). Least no. of aphids were consumed on when reared on cotton (85.75±34.15 aphids) followed by sunflower (109.25±10.71 aphids).

The predatory capacity of adult male beetle was highest when fed with aphids reared on groundnut (588.5±27.57 aphids) (significantly different), greengram (539.23±32.13 aphids), cowpea (519.5±14.84 aphids) and blackgram (509.00±37.87 aphids). Least amount of aphids were consumed by the adult male beetle when reared on cotton (425.00±17.89 aphids) and sunflower (469.11±28.46 aphids).

The predatory capacity of adult female beetle was highest when fed with aphids reared on groundnut (903.00±39.59 aphids) (significantly different) followed by blackgram (797.33±20.40 aphids), greengram (757.66±25.02 aphids), cowpea (519.5±14.84 aphids) (significantly different). Least amount of aphids were consumed by the adult male beetle when reared on cotton (528.00±12.72 aphids) and sunflower (547.00±9.89 aphids).

During the entire life span of the beetle (including both larval and adult stages) highest no. of aphids were consumed when aphids were reared on groundnut (975.00±191.38 aphids) followed by blackgram (937.75±158.17 aphids), greengram (917.25±79.83 aphids), cowpea (797.25±88.85 aphids). Least numbers of aphids were consumed, when aphids were reared on cotton (456.00±284.77 aphids) and sunflower (500.00±265.32 aphids).

CONCLUSIONS

1. Among all the tested host plants, the preference ranks are (most preferred to least preferred) of host plants for *A. craccivora* are cowpea> groundnut> greengram> blackgram> sunflower> cotton.

2. Highest body size (body length and body width) of aphids were obtained, when they were reared on cowpea followed by greengram, blackgram and groundnut.

3. Higher trichome density, phenol content and reducing sugars in leaves of cotton and sunflower caused highest nymphal mortality of *A. craccivora*.

4. Comparatively higher proteins, free amino acids, total soluble sugars and less trichome density, phenols and reducing sugar content in cowpea leaves were preferred by aphids for growth and development.

5. When aphids reared on different host plants were fed to lady beetle *C. sexmaculata* , total larval duration was longest on groundnut reared aphids followed by blackgram> greengram> sunflower> cowpea> cotton.

6. During the entire larval duration *C. sexmaculata* consumed highest no. of aphids, when aphids were reared on groundnut followed by greengram> blackgram> cowpea> cotton> sunflower.

7. During the entire life span, *C. sexmaculata* consumed highest no. of aphids when aphids were reared on groundnut followed by blackgram, greengram, cowpea, sunflower and cotton.

8. Due to low nutritional status of groundnut plants, aphids reared on these plants were smaller, low in their nutritional status and hence the both grubs and adults of *C. sexmaculata* consumed more number of aphids and also took longer period of time to complete their life cycle.

9. Because of high nutritional status of cowpea, nymphs and adult aphids preferred this more as compared to others and were bigger in size. Subsequently, because of high nutritional status of aphids reared on cowpea both grubs and adults of *C. sexmaculata* consumed fewer numbers of aphids and took less time to complete their life cycle.

FUTURE LINE OF WORK

1. Studies of use of susceptible cowpea cultivar as trap crop in *A. craccivora* problematic area.

2. Screening of different cowpea cultivars against *A. craccivora*.

3. Study of tri-trophic interaction of different host plants, *A. craccivora* and natural enemies such as other predatory coccinellid beetles (*Coccinella septempunctata, Scymnus craccivora* etc.), syrphids (*Ephisyrphus balteatus, Sphaerophoria javana, Paragus serratus* etc.) and lace wings (*Chrysoperla carnea, Micromus* sp., *Hemerobius* sp. etc.) etc. available in agoecosystems.

4. Bioassay studies of insecticides to *A. craccivora* with respect to host plant resistance.

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