LIFE TABLE, FEEDING POTENTIAL AND RELATIVE TOXICITY OF INSECTICIDES TO LADYBIRD BEETLE, *Cheilomenes sexmaculata* (Fabricius)

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Life table, feeding potential and relative toxicity of insecticides to ladybird beetle, *Cheilomenes sexmaculata* (Fabricius)

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ABSTRACT

Investigations on "Life table, feeding potential and relative toxicity of insecticides to ladybird beetle, *Cheilomenes sexmaculata* (Fabricius) were carried out at Department of Agricultural Entomology, B. A. College of Agriculture, Anand Agricultural University, Anand (Gujarat) during the year 2019-20. The feeding potential of the predator was calculated on four hosts *i.e.*, mustard aphid, *Lipaphis erysimi* (Kaltenbach), cotton aphid, *Aphis gossypii* (Glover), maize aphid, *Rhopalosiphum maidis* (Fitch) and cowpea aphid, *Aphis craccivora (*Koch). A total of nine insecticides, *viz.*; acetamiprid (0.006%), buprofezin (0.05%), fipronil (0.01%), flonicamid (0.015%), imidacloprid (0.089%), spinosad (0.0135%), spiromesifen (0.0229%), thiacloprid (0.013%) and thiamethoxam (0.01%) were evaluated.

On the basis of the observation made for the life table studies of *C. sexmaculata* reared on *A. gossypii*, the net reproductive rate (R_0) 129.47 was obtained with a mean length of generation (T) 26.81 days. The intrinsic rate of natural increase in numbers (r_m) was 0.1871 females per female per day and the population would be able to multiply 3.7034 times per week. The hypothetical F_2 females were worked out to be 16,763.69. The life expectancy of *C. sexmaculata* declined gradually with the advancement of development. The life expectancy of newly deposited eggs was 10.70 days.

Results of feeding potential revealed that highest (20.13±0.61) number of aphids consumed by first instar in *A. craccivora*. Second instar preferred *R. maidis* (35.27±0.49), while third and fourth instar larvae fed more on *A. gossypii*, with consumption of 57.87 ± 47 and 79.60 ± 1.99, respectively. It indicated that aphid consumption increased with the advancement of larvae from first to fourth instar, maximum being in case of fourth instar. The total consumption of grubs revealed that grubs of *C. sexmaculata* fed mere on *A. gossypii* (191.20±4.17) closely followed by *A. craccivora* (177.10±5.48). The consumption capacity of *C. sexmaculata* adult indicated that *A. craccivora* (820.30±44.94) followed by *A. gossypii* (739.93±28.96). The least number of aphids eaten during grub and adult period was of *L. erysimi* (105.73±3.83 and 441.33±40.35). The total consumption by *C. sexmaculata* in its entire life time was more on *A. craccivora* (997.40±45.60). The consumption ability of *C. sexmaculata* adults to different species of aphids can be arranged in descending order as: *A. craccivora* > *A. gossypii* > *R. maidis* > *L. erysimi.*

The analysis of relative toxicity of insecticides against eggs, grubs and adults of *C. sexmaculata* showed that acetamiprid, thiacloprid and spinosad showed more than 50 % mortality. Imidacloprid, spiromesifen and fipronil were relatively less toxic to the predator than spinosad. While flonicamid, buprofezin and thiamethoxam proved safer insecticides to the adults of *C. sexmaculata.*

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CERTIFICATE

This is to certify that the thesis entitled **“Life table, feeding potential and relative toxicity of insecticides to ladybird beetle, *Cheilomenes sexmaculata* (Fabricius)”** submitted by **Ms. Neelam A. Singh** in partial fulfillment of the requirements for the award of the degree of **Master of Science (Agriculture)** in **Agricultural Entomology** of the Anand Agricultural University is a record of bonafide research work carried out by her under my personal guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma or other similar title.

Place : Anand
Date : / /2020

(M. R. Dabhi)
Major Guide

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Date: / /2020

Place : Anand ***(Neelam A. Singh)***

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LIST OF ABBREVIATIONS

& : And
@ : At the rate of
°C : Degree Celsius
= : Equal to
− : Minus
× : Multiply
/ : Per
% : Per cent
+ : Plus
a.i. : Active ingredient
AAU : Anand Agricultural University
Anon. : Anonymous
BACA : B. A. College of Agriculture
C. V. : Coefficient of Variation
cm : Centimeter
Conc. : Concentration
d^{-1} : per day
DNMRT : Duncan’s New Multiple Range Test
EC : Emulsifiable Concentration
et al. : Et allii; and others
etc. : Etcetera
g : Gram
ha : Hectare
hrs. : Hours
ICAR : Indian Council of Agriculture Research
kg : Kilogram
l : Litre
L : D : Light hours and day hours
Ltd. : Limited
Max. : Maximum
Min. : Minimum
ml : Millilitre
No. : Number
NS : Not significant
ppm : Parts Per Million
S. Em. : Standard Error of mean
SC : Suspension Concentrate
SG : Soluble Granules
Sig. : Significant
SL : Soluble Liquid
SP : Soluble Powder
viz. : Videlicet, Namely
WG : Wettable Granules
WP : Wettable Powder

CONTENTS

1. INTRODUCTION

The protection of crops has remained one of the major initiatives since the beginning of commercial agriculture era among the researchers. The insect pests' having a greater impact on the crop losses has to be controlled by various means. Today, the world is bending towards the natural or organic agriculture *i.e.* limited or no use of chemical insecticides. This has caused the waves to turn toward the past, towards traditional techniques and natural means for crop protection. Now-a-days several tactics are adopted in Integrated Pest Management (IPM) program. The management strategy for each type of pest being different, control operations are complex and highly technical in IPM involves to take a series of steps for keeping the pest population below economic threshold level which demand the use of resistant varieties, timely sowing/planting, uses of pheromones, suppression of pest through biological agents, judicious use of pesticides *etc*. Among greatest methods of pest management, the biological control is a living weapon over chemical control and is prestigious method adopted at global level (Tank, 2006).

Biological control is the most economical, eco-friendly and effective approach involving the utilization of natural enemies such as predators, parasitoids and pathogens. It has long been recognized as core component of IPM and has assumed significance. DeBach (1964) defined biological control as "the action of parasitoids, predators and pathogens in maintaining other organism density at a lower average than would occur in their absence." Suppression of pest population through predation is known to mankind since ancient times. The predators are important natural enemies of crop pests, which directly attack and kill the other species (prey or host). It is the corner stone of IPM, along with host-plant resistance is central to the pest management paradigm (Ananthakrishnan, 1996).

The predaceous coccinellids under the order coleoptera and family coccinellidae are linked to biological control more than any other taxa of predatory organisms. The members of this family occupy all the habitats and niches of their preys and distributed worldwide. It is one of the important predators of aphids, mealybugs, scale insects, whiteflies, thrips, leafhoppers, mites and other small soft-bodied insect pests (Omkar and Pervez, 2000). They are holometabolous insects and possess five stages in their life cycle *i.e.*, egg, larva, pre-pupa, pupa, and adult. There are three molting and four larval instars. It attacks more than 39 arthropod species (Gautam, 1989). The beneficial status of these organisms has a rich history which has been recognized by many biological control practitioners (Hodek and Honek, 1996; Hodek and Honek, 2013). Coccinellids are known to have the strongest impact among all aphidophagous insects in aphid population regulation (Hodek, 1970; DeBach and Huffaker, 1971).

There was a time when this group of insects used to catch the attention of people, especially children, primarily because of their colors, but for more than a century it has been established that most of the species are natural enemies of many insect and acarine pests, only with the exception of subfamily Epilachninae which is mostly phytophagous. The term "Lady" in ladybird beetles, denotes the Lady, the Virgin Mary and is derived from a commonest British species, seven- spotted ladybird, *Coccinella septempunctata* (Linnaeus). Its seven spotted red coloured elytra resemble her red coloured cloak, which in early paintings and sculptured were usually depicted as being red and the seven black spots represent the seven joys and seven sorrows of the Mary. Due to this gracious fact, the ladybirds are loved and considered as the heralds of good fortune and tidings (Majerus and Kearns, 1989). The ladybird was immortalised in the popular children's nursery rhyme "Ladybird Ladybird":

Ladybird, ladybird, fly away home,
Your house is on fire and your children are gone,
All except one, and that's Little Anne,
For she has crept under the warming pan.

In different countries ladybird beetles are named after the natural positive things. The native of Czech Republic call them as "Slunicxa" meaning small suns. In Japan, they are considered as sun loving insects therefore referred as "Tentomunshi". The Vikings dedicated the seven- spotted ladybird beetle to Frigg, the wife of Odin and goddess of domestic conjugal love and called it as "Friggahonna" (Dixon, 2000). In India, they are recognized by different names in different languages. In Hindi, it is called "Indragop", while in Gujarati it is known as "Daliya".

Approximately 6000 known species of coccinellidae have been recorded (Vanderberg, 2000). Among them, more than three hundred species of predaceous coccinellids have been reported from India (Poorani, 2004; Satpathy *et al.*, 2009). This shows their amplified enriched existence and vast dispensation in all over the world. They also possess high dispersal capacity, due to which an introduced coccinellid rapidly and easily expand its sphere of influence and invade most of its prey site in a short span of time.

The first spectacular achievement in the field of biological control was the use of *Rodolia cardinalis* Muls. for controlling cottony cushion scale, *Icerya purchasi* Mask. in citrus orchards (Doutt, 1964). Exhaustive documentation on the ecology (Hodek and Honek, 1996; Hodek *et al.*, 2012), prey–predator dynamics (Dixon, 2000; Hirose, 2006), distribution, and native ladybird beetles (Majerus, 1994) have been published since the year 2000. Ladybirds are uniquely referred to as a component of ‘‘***biological services***” (Landis *et al.*, 2008). It is one of the beautiful insects found in all parts of the world. Ladybird beetle’s immature and adult stages play important role in biological ecosystems and have been used in different regions of the world to manage pests such as aphids, mealy bugs, thrips and mites (Tank *et al.*, 2010). These are important bio-suppression agents of aphids and occupy a unique place among the aphidophagous predators by virtue of their wide distribution and good predating ability both in larval and adult stages. A large number of species of this group have been very effective in bringing down the field population of aphids (Chowdhari and Pal, 1975).

In India, the species of ladybird beetles such as *C. septempunctata, Coccinella transversalis* (Fabricius), *Brumoides suturalis* (Fabricius) and *Cheilomenes sexmaculata* (Fabricius) (*Menochilus sexmaculatus* (Fabricius)) are most wide spread. Among these, *C. sexmaculata* is a predominant species in middle Gujarat (Patel *et. al.,* 1976) which plays a very important role in checking aphid population in groundnut. According to them, because of the activities of the natural predators, the peak incidence of aphid virtually disappeared after a week. Due to this, there is no need of application of insecticide in summer groundnut to control the aphid infestation, if ladybird beetles are present in the crop (Butani and Bharodia, 1984).

C. sexmaculata is a species of ladybird beetle. It was described by Johan Christian Fabricius in 1781. It is well known as a predator of aphids and other small insects. Although sometimes known by the common name of six-spotted zigzag ladybird, this is misleading as there are several colour morphs and some colour morphs of the species can be confused with *Micraspis discolor* (Fabricius) and *Chilocorus nigritus* (Fabricius). The species has a wide distribution range within the Asian tropics and subtropical zones from India to Japan and parts of the Australian region. They have been introduced into the Caribbean islands as a biocontrol agent and their spread to South America was noted in 2019. The elytral colour has been identified as being controlled by two genes with two alleles each U-u and D-d and the phenotypes have been grouped into varieties *quadriplagiata* (“Q”) [UUDD, UUDd, UuDD, UuDd]; *unifasciata* (“U”) [Uudd, UUdd] ; *diversijunata* (“D”) [uuDD, uuDd] and *sexmaculata* (“S”) [uudd]. The darker forms predominate in higher latitudes where absorption of heat may aid their survival.

The beetle is found to be active throughout the year in many parts of India with many generations. The important features of *C. sexmaculata* includes its wide geographic distribution and host range, broad habitats, resistance/ tolerance to certain pesticides, enhanced searching ability, voracious larval feeding capacity and easy rearing in laboratory (Venkatesan *et al.*, 2006). High value of the life history parameters, *viz.*; developmental rate, immature survival, fecundity, egg viability, reproductive rate and conversion of efficiency of ingested food it has the intrinsic advantages over two coexisting coccinella species (Omkar *et al.*, 2005). This predator has a significant potential of commercialization and use against a variety of pests in combination with other integrated pest management tactics. Various works has been in progress on a very large scale use of *C. sexmaculata* in different countries leading to development of large-scale mass production technology (Pirasanna *et al.,* 2012).

In today’s time, when IPM has become an integral part of the crop protection aspects of agriculture and in the wake of the threat posed by the indiscrimate use of chemical pesticides the need to find the alternatives has become apparent. Biological control can be one of the solutions. But to effectively implement this solution the detailed knowledge about the species and insects included should be known through various researches. An attempt has been made here to reveal the details about one of the most important bio-agent *i.e.* ladybird beetle.

Life table analysis is a standard ecological method to estimate demographic parameters related to population dynamics (Legaspi, 2004). Life table gives the most comprehensive explanation of the survivorship, development, and reproduction of a population. Feeding potential is one of the most important factors which determine the use of natural enemies as bio-control agents in integrated pest management. The collection of life table data for relevant species at different trophic levels in a food chain is a basic and important task for conservation (Bevill *et al.*, 1999) or pest management (Naranjo, 2001). The type of functional response, that is the shape of the relationship of the number of prey eaten to the prey available, influences the dynamics of the predator population and may contribute to the stability of predator - prey system. By correlating studies on the predation rate and life table and by considering variations due to age, stage, and sex into account, the growth, stage variability, reproduction, and the predation rate can be effectively characterized (Chi and Yang, 2003).

The amount of prey consumed affects on development, survival and reproduction of predators, so one must study predator responses to these factors to understand the ecology of predators including the searching behaviour, foraging efficiency and prey consumption. The outcome of the biological study will be helpful for mass-multiplication of the bio-agent (Chakraborty, 2012).

The modern agriculture receives heavy input such as fertilizers, chemicals for better yield. Hence insect pest are controlled by insecticides, which is not only expensive but also it’s residues left over the sprayed surface of the crops or in the soil and have turn out to be a subject of concern of environmental pollution. The indiscriminate use of pesticides causes phytotoxicity and death of beneficial organisms such as parasites, parasitoids, micro-organisms and pollinators (Southwood and Henderson, 2000). There is an urgent need to develop suitable and safer insecticides against *C. sexmaculata*.

Thus, for the perseverance from chemical insecticides, more effective use of these natural enemies in biological control of pests and to insight the knowledge on above mentioned aspects the present study is carried out with following objectives.

OBJECTIVES:

1. To construct life table of *C. sexmaculata*
2. Feeding potential of *C. sexmaculata* on different species of aphids
3. To evaluate the relative toxicity of some insecticides to *C. sexmaculata*

2. REVIEW OF LITERATURE

An attempt has been made to review the available work which has direct or indirect relation with the present investigation on life table construction, feeding potential against various host species of aphids and relative toxicity of various insecticides against *Cheilomenes sexmaculata* (Fabricius). The literatures pertaining to these aspects published in various scientific literatures in India and abroad has been reviewed and presented under the following headings:

2.1. Life table construction of *C. sexmaculata*

Birch (1948) defined the intrinsic rate of increase as the actual rate of increase of population under specified environmental condition in which space and food were unlimited. There were no mortality factors other than physiological one.

Howe (1953) suggested that a life table could be constructed by following the life history of a group of insects from the deposition of eggs to successful adult emergences, as all deaths occur together in adult stage. He also suggested that the food mainly influenced the rate of increase and the effect was expressed through development stages of insects.

Omkar *et al.* (2004) studied the reproductive attributes, such as, pre-oviposition, oviposition and post-oviposition periods, fecundity, per cent egg-viability and mean reproductive rate, along with age specific fecundity, clutch size and natality based demographic parameters of an aphidiophagous ladybird beetle, *C. sexmaculata* using cowpea aphid, *Aphis craccivora* (Koch) as prey. The high fecundity of 1892.8 ± 205.30 eggs was obtained, which appears to be a record reproductive output by female beetle feeding on any aphid species. Both age-specific fecundity and clutch size were triangular and of similar shapes, revealing their interdependence. Age-specific viability was not affected with increase in female age, however, decreased in old age female, exhibiting the effect of senescence on the progeny. The net reproductive rate (R_o), intrinsic rate of increase (r_m) and generation time was 1092.94, 0.1516 d^{-1} and 46.17 days, respectively. The high values of R_0 and r_m are attributed to the high female-biased sex ratio of the offsprings, high survival and high net fecundity. These high demographic values encourage the mass-multiplication of

C. sexmaculata in the laboratory and predict the possible successful establishment of the predators in the habitats containing *A. craccivora* infestation.

Ali and Rizvi (2009) gauged the age specific life table of *Menochilus sexmaculatus*, revealed that it took shortest development period in 28 ± 1°C and longest in 20 ± 1°C. However, a sharp decline in expectation of life (e_x) towards the end of generation was seen specifically at 28 ± 1°C as compared to other temperatures. As far as stage specific life table was concerned, the development stages of *M. sexmaculatus* attained minimum apparent, indispensable mortality, mortality survival ratio and maximum survival at 20 ± 1°C as well as 24 ± 1°C. Similarly the total generation mortality (K) was recorded minimum at 24 ± 1°C followed by 20 ± 1 and 28 ± 1°C. The study exhibited that among three different constant temperatures, 20 ± 1°C followed by 24 ± 1°C has been proved as a most suitable for the development of *M. sexmaculatus*.

According to Ali and Rizvi (2010), the data on age and stage specific life-table of *Coccinella septempunctata* at varying temperature revealed that it took maximum period to complete generation at 20 ± 1°C followed by at 24 ± 1°C and at 28 ± 1°C. The survivorship and mortality curve showed an irregular pattern with sharp high peaks and negative low peaks. The expectancy of life exhibited a continuous decline with advancement of age. As far as stage specific life table concerned, the developmental stages of *C. septempunctata* showed highest survivor fraction and lowest apparent mortality, mortality survival ratio, indispensable mortality and k-values at low temperature as compared to high. On the other hand, minimum total generation mortality (K) was recorded at 24 ± 1°C followed by 20 ± 1 and 28 ± 1°C. The study revealed that among three different constant temperatures, 24 ± 1°C has been proved as a most suitable for the life cycle of *C. septempunctata*.

Zhao *et al.* (2015) constructed life tables for *C. sexmaculata* fed on *Myzus persicae* (Sulzer) both at constant temperature in the laboratory and fluctuating temperature in the greenhouse, and analyzed the data using the age-stage, two-sex life table. The results showed that the intrinsic rate of increase (r_m), net reproductive rate (R_0), and finite rate of increase (k) under laboratory and greenhouse conditions were 0.1668 d^{-1} and 0.1027 d^{-1} , 192.1 and 53.0, and 1.1815 d^{-1} and 1.1082 d^{-1}, respectively.

Their results revealed significantly different life table parameters for *C. sexmaculata* under laboratory and greenhouse conditions.

Farooq *et al.* (2018) collected the data of life table and predation for *C. septempunctata* feeding on three different host aphid species *viz.*; *A. craccivora*, *Lipaphis erysimi* (Kaltenbach) and *M. persicae* under laboratory conditions, using age-stage, two-sex life table. The pre-adult developmental period of *C. septempunctata* was shortest on *M. persicae* and longest on *A. craccivora*. Net reproductive rate (R_0) ranged from 77.31 offspring per individual on *A. craccivora* to 165.97 offspring per individual on *M. persicae*. Mean generation time (T) ranged from 39.10 days on *M. persicae* to 51.96 days on *L. erysimi*. Values of the intrinsic rate of increase (r_m) decreased in the order *M. persicae*, *A. craccivora* and *L. erysimi*. The highest finite rate of increase (λ) was on *M. persicae* (1.1391 d^{-1}) and the lowest was observed on *A. craccivora* (1.0903 d^{-1}) and *L. erysimi* (1.0885 d^{-1}).

Abbas *et al.* (2020) conducted an experiment under laboratory condition at 25 ± 2 °C, 60 ± 5 % relative humidity and L14: D10 hrs. The pre-adult development duration of *M. sexmaculatus* was maximum when fed on *M. persicae* (12.18 days) and minimum on *Diuraphis noxia* (Kurdjumov) (10.64 days). Similarly, male and female duration was maximum on *M. persicae* (26.70 days), minimum on *L. erysimi* (23.67 days) in male and in female maximum on *D. noxia* (28.00 days) and minimum on *Aphis nerii* (Fonscolombe) (24.33 days). Net reproductive rate (R_o) ranged from 117.9 on *L. erysimi* to 99.55 on *M. persicae* and intrinsic rate of increase (r) range was 0.21197 d^{-1} on *A. nerii* to 0.021559 d^{-1} on *D. noxia*. The finite rate of increase (λ) range was 1.240592 d^{-1} on *D. noxia* to 1.204918 d^{-1} on *M. persicae*, the mean of generation (T) was 24.68 d^{-1} on *M. persicae* to 22.476 d^{-1} on *A. nerii*. Similarly, the gross reproductive rate (GRR) was 172.2 d^{-1} on *D. noxia* to 115.02 d^{-1} on *M. persicae* and fecundity (F) eggs per female range was 316.8 on *D. noxia* to 199.1 on *M. persicae*.

2.2. Feeding potential of *C. sexmaculata* on different species of aphids

Azim and Ahmed (1967) reported that the *M. sexmaculatus* attacked all forms of the aphid, *A. craccivora*. The average daily number of aphids consumed per larva generally increased with age from 17.20 for larvae of one day old to 50 for larvae of eight days old, the overall average being 23.20 aphids per day. The number of aphids consumed daily by the adults was varied from 12 to 50 with an average of 32.40.

Sharma (1973) evaluated the feeding potential of *M. sexmaculatus* on various host aphids. According to him, the adults of *M. sexmaculata* consumed an average of 20.60, 21.00, 31.30, 29.00, 17.60 and 12.00 individuals of *Brevicoryne brassicae* (Linnaeus), *Macrosiphum pisi* (Linnaeus), *L. erysimi, A. craccivora, Aphis gossypii* (Glover) and *Rhopalosiphum maidis* (Fitch) during 24 hrs., respectively.

Patel and Vyas (1984) noted that the number of *A. craccivora* nymphs consumed during 6 days of grub period varied from 87 to 120 with an average of 100.38, whereas it ranged from 120 to 764 with an average of 373.62 during 16 to 49 days of adult life. Thus on an average 474.00 aphid nymphs were consumed during grub and adult stages of *M. sexmaculatus*.

Patel (1985) observed that the average number of *A. craccivora* consumed by the predatory grub of *M. sexmaculatus* during its first, second, third and fourth instar were 7.60, 16.28, 23.39 and 26.51 aphids per day, respectively. The total average number of aphids consumed by the predatory grub during its first, second, third and fourth instar were 10.87, 24.28, 35.39 and 36.51 aphids per individual, respectively. Predatory capacity of the grub during its total grub duration was varied from 47 to 121 aphids with an average of 107.05 aphids. The adult of *M. sexmaculatus* was able to prey an average of *A. craccivora* (28.28), *R. maidis* (26.51), *A. gossypii* (16.60) and *Longiunguis sacchari* (Zehentner) (8.80) adults.

According to Lokhande and Mohan (1990), the average consumption of each larva per day was 8.50 adults and 73.52 nymphs of *A. craccivora*. The adult coccinellids consumed 24.34 adult aphids and 176.15 nymphs per day.

Das (1991) reported that the feeding rate of *M. sexmaculatus* larvae during its first day after hatching ranged between 9.0 and 13.0 adults of *A. craccivora* (average 10.95±0.32). From the second day, the rate of consumption gradually increased to reach an average of 53.03 ± 0.93 aphids on the 8th day after which feeding rates fall sharply. One larva consumed 270 to 367 aphids with an average of 312.90 ± 6.91 prior to pupation.

Verma *et al.* (1993) estimated that the larva of *M. sexmaculatus* consumed 598.5 ± 45.8 *A. gossypii* during its life time. A male consumed 206.20 ± 21.1 aphids, whereas the female consumed 277.10 ± 41.5 aphids.

Zala (1995) observed that the average number of *L. erysimi* consumed by the predatory grub of *M. sexmaculatus* during its first, second, third and fourth instars were 8.12, 15.02, 21.76 and 25.10 aphids per day, respectively. The average numbers of aphids consumed by the predatory grub during their individual instar were 18.5, 41.2, 66.70 and 66.60 aphids, respectively. Average number of aphids consumed during entire grub and adult period was 193.00 and 507.30 aphids, respectively.

As per the report of Patel (1998) the predatory potential of first, second, third and fourth instar larvae of *M. sexmaculatus* on maize aphid, *R. maidis* was on an average of 8.26, 15.10, 20.77 and 23.50 aphids per day, respectively.

Predatory potential of *C. sexmaculata* studied in laboratory by Tank (2006) revealed that the average number of *A. gossypii* consumed per day by first, second, third and fourth instar larvae were 9.74 ± 2.44, 15.54 ± 3.28, 26.15 ±1.86 and 38.73 ± 2.77, respectively. An individual beetle consumed 12 to 77 with an average of 32.34 ± 7.14 aphids. The number of *A. gossypii* nymphs consumed by the coccinellid beetle ranged from 243 to 987 with an average of 607.57 ± 199.39. Among the six different species of aphids used to determine the comparative consumption ability of *C. sexmaculata* adults, significantly highest (29.48 aphids/day) number of lucerne aphid were consumed by the beetle which was closely followed by cotton aphid *A. gossypii* (28.94 aphids/day). Mustard aphid, *L. erysimi* and maize aphid, *R. maidis* were equally preferred by the adults.

Solangi *et al.* (2007a) observed the feeding efficiency of grub on *R. maidis*, *A. gossypii* and *Therioaphis trifolii* (Monell). They observed that mean number of aphids fed by first, second, third and fourth instar larvae were 6.20, 20.82, 55.00 and 115.87 on *R. maidis* 6.40, 20.00, 30.50 and 43.27 on *A. gossypii* and 12.00, 27.00, 44.20 and 145.27 per day on *T. trifolii*. Prey consumption by the grub was found to be highly significant between third and fourth instars but non-significant between first and second instars. Fourth instars and adult *M. sexmaculatus* consumed more *R. maidis* than the other two aphid species. Mean number of aphids consumed by first to fourth instars was 49.47, 25.04 and 57.11 of *R. maidis, A. gossypii* and *T. trifolii* respectively. Mean fecundity of the female was 642, 530 and 600 eggs when fed on *R. maidis*, *A. gossypii* and *T. trifolii,* respectively. Egg hatchability percentage of the beetle was 65.42 with *R. maidis*, 64.33 with *A. gossypii* and 70.69 with *T. trifolii*.

Feeding potential of *C. sexmaculata* on *L. erysimi* was studied in the laboratory at 27 ± 2°C and 70 ± 5% relative humidity by Singh *et al.* (2008). The pooled mean feeding potential of grub and adult was 26.82 ± 0.59 and 47.13 ± 1.75 aphids per day per individual, respectively.

Singh *et al.* (2009) investigated the feeding potential of *C. septempuncata* on mustard aphid, *L. erysimi*. The mean fecundity was 357.45 ± 22.41 eggs per female. While, ovipositional period, incubation period, larval period, pupal period, total developmental period and adult longevity were 4.32 ± 0.26, 4.40 ± 0.22, 10.95 ± 0.35, 5.35 ± 0.15, 20.70 ± 0.72 and 122.90 ± 3.12 days, respectively. The mean feeding potential of grub and adult was 50.38 ± 1.56 and 83.54 ± 1.15 aphids per day per individual, respectively.

Prabhakar and Roy (2010) assessed the consumption rate of coccinellid predators on aphid *viz.*; *A. craccivora, A. gossypii, M. persicae* and *L. erysimi*. The results concluded that the adult of *C. septempunctata, C. transversalis, C. sexmaculata, M. discolor* and *Pulus pyrochilus* had high consumption rate on *A. craccivora* (65.60±3.01, 52.00±4.2), followed by *L. erysimi* (57.00 ±4.4, 41.25±1.7), *A. gossypii* (57.00±2.26, 39.50±0.55), *M. persicae* (43.40±0.51, 30.66±0.62) and *L. erysimi* (34.75±1.4, 25.2±0.65).

Chakraborty (2012) revealed that total consumption of aphids by both the feeding stage (grub and adult) of *C. sexmaculata* was varied from 215.67 to 392.25. Significantly highest (392.25±10.24) numbers of *A. craccivora* individuals were consumed by the predator than individuals of other species of aphids. *A. gossypii* was also found to be a preferred host for *C. sexmaculata* next to *A. craccivora*. The predator consumed 306.75 ± 5.73 individuals during its entire life. *A. nerii* and *L. erysimi* proved less preferred host for *C. sexmaculata* as 223.92 ± 8.31 and 215.67 ± 6.62 individuals were fed by the predator, respectively.

Pirasanna *et al.* (2012) carried out a laboratory study to find out the feeding potential of coccinellid predator, *C. sexmaculata* on aphid hosts *viz.*; *A. craccivora*, *A. gossypii, R. maidis* and *L. erysimi*. The fourth instar grubs consumed significantly more aphids when compared to first, second and third instars. The per day predation rate by female ladybird beetle on *A. craccivora* was 37.20 ± 3.32, followed by *A. gossypii* (35.20±2.22) and *L. erysimi* (23.00±0.94). The male could feed mostly on *A. craccivora* (35.80±2.67) followed by *A. gossypii* (30.80±1.98), *R. maidis* (27.80±4.28) and *L. erysimi* (20.80±1.15).

Singh *et al.* (2012) studied predation potential of grubs and adults of ladybird beetle, *C. septempunctata* on mustard aphid, *L. erysimi* in *rabi* season of 2007-2008 and 2008-2009. The number of aphids preyed by developing instars remained quite low, being 17.03, 44.50, 64.66, 91.60, 64.18 and 92.34 during 2007-2008, while during 2008-2009 it was 18.32, 47.30, 73.33, 93.28, 65.05 and 92.92 aphids per day by first, second, third and fourth instars grub and adult male and female of *C. septempunctata*, respectively.

Kassi *et al.* (2016) investigated the feeding potential, oviposition, larval and pupal stages of ladybird beetle, *C. septempunctata*. It was observed that feeding potential of the first, second, third and fourth larval instars of *C. septempunctata* were affected significantly by host density. For the feeding potential of *C. septempunctata* the aphids offered were 17.0, 20.0, 20.0 and 30.0. The average aphids consumed were 9.0 ± 0.10, 12 ± 0.80, 12.4 ± 1.1 and 23.0 ± 1.4 by the first, second, third and fourth instars of *C. septempunctata* grubs, respectively. Feeding potential increased while the host density increased significantly 9.00 ± 0.10, 12.00 ± 0.80, 12.40 ± 1.1 and 23.00 ± 1.4. The *C. septempunctata* consumption percentage was also increased 52.90 ± 0.60, 60.0 ± 4.00, 62.1 ± 5.81 and 85.4 ± 1.90 on all the grub instars, respectively.

Priyadarshani *et al.* (2016) studied *M. sexmaculatus* and observed that first, second, third and fourth instar larvae consumed aphid nymphs at the rate of 10.30 ± 1.9, 7.50 ± 1.30, 38.10 ± 3.50 and 69.10 ± 3.10 per day, respectively and consumed adult aphids at the rate of 3.30 ± 0.60, 3.30 ± 0.60, 12.10 ± 0.90 and 25.10 ± 1.70 per day, respectively. Female beetles consumed 1624.10 ± 0.20 nymphs and 1204.30 ± 1.30 adult aphids during their entire adult life span. Males consumed 1302.00 ± 1.50 nymphs and 1006.40 ± 0.40 adult aphids during their entire life span. The feeding efficacy increased with the larval instars. Feeding efficacy of *M. sexmaculatus* adults was higher than larvae.

Ali *et al.* (2017) estimated that the maximum mean consumption by adults of *C. septempunctata* was observed against green aphid, *M. persicae* (408.33), whereas, 55.22, 102.66, 172.00 and 315.00 aphids were consumed by first, second, third and fourth larval instars as compared to black and yellow aphids. The short larval and pupal durations of *C. septempunctata* were observed against green aphids 13.33 ± 0.33 and 6.33 ± 0.33 (days) respectively, while a longer time period was noticed by adult stage when fed on green aphids as compared to black, *A. craccivora* and yellow aphids, *A. gossypii*.

Vasista (2019) studied the predatory potential for *C. sexmaculata* on two aphid hosts *viz.*; *A. craccivora* and *A. gossypii*. First, second, third, fourth instar grubs, adult male beetle and adult female beetle of *C. sexmaculata* consumed 11.60 ± 1.16, 36.80 ± 1.77, 57.80 ± 4.95, 121.00 ± 8.63, 764.00 ± 23.89 and 940.00 ± 21.62 adults of *A. craccivora* respectively. First, second, third, fourth instar grubs, adult male beetle and adult female beetle of *C. sexmaculata* consumed 8.20 ± 0.58, 24.60 ± 1.50, 38.60 ± 0.74, 115.20 ± 3.04, 593.20 ± 11.46 and 730.00 ± 14.32 adults of *A. gossypii* respectively. Also it consumed 1167.20 ± 28.83 and 949.80 ± 44.90 adults of *A. craccivora* and *A. gossypii* respectively in its entire life cycle.

2.3. Relative toxicity of insecticides against *C. sexmaculata*

Satpathy *et al.* (1968) observed that thiometon, methyl demeton, phosphamidon, mevinphos and dimethoate exhibited low to moderate toxic, whereas malathion was found more toxic to the adults of *C. sexmaculata* in laboratory.

Gupta and Kushwaha (1970) found that out of five insecticides tested at three different concentrations to *C. septempunctata*, the mortality in case of thiometon was significantly least at 8, 16 and 24 hrs. following the treatment. Parathion gave significantly less mortality than phosphamidon and dichlorvos only upto 16 hrs. The ascending order of toxicity of the tested insecticides to the predator was thiometon < lindane < parathion < dichlorvos < phosphamidon.

Singh and Malhotra (1975) studied the mortality of adult of *C. septempunctata* when feeding on aphid treated with different insecticides. The lowest mortality was observed when aphids were treated with endosulfan, chlorfenvinphos and menazon. While higher mortality was observed when aphids were treated with malathion and diazinon.

Lingappa *et al.* (1978) experimented on the adults of *M. sexmaculatus*. The adults were treated with fresh spray deposits of malathion (0.1%), phosalone (0.07%) and endosulfan (0.07 %) in the laboratory and found that all the beetles were killed in 2, 4 and 24 hrs., respectively. On deposits 7 days old of the three treatments, the mortalities in 24 hrs. were 100, 44 and 0%, respectively.

Singh *et al.* (1979) worked on safety margin of nineteen insecticides for the grubs of aphid predator, *C. septempunctata* through bioassay technique. The relative toxicity values were higher in case of phorate, phosphamidon, diazinon, malathion, formothion, phenthoate and methyl parathion as compared to ethyl parathion. While the lower relative toxicity values were found in case of fenitrothion, orthodibrom, dichlorvos, rotenone, leptophos, trichlorphon, lindane and p-p DDT. However, the least toxic insecticides were aphidan, endosulfan and nicotine sulphate, which gave less than 50 % mortality even at 1 % concentration.

Makar and Jadhav (1981) evaluated the toxicity of ten insecticides against the larvae and adults of *M. sexmaculatus* under laboratory conditions and found that endosulfan, chlorfenvinphos, thiometon and monocrotophos were less toxic, while carbaryl, fenitrothion and quinalphos were highly toxic causing 95-100 % mortality in 72 hrs. after treatment; demeton-methyl, phosphamidon and dimethoate were moderately toxic. Larvae were less susceptible to all the compounds than adults.

Singh and Sircar (1983) determined the toxicity of seven insecticides *viz.*; phorate, dimethoate, phosphamidon, carbaryl, endosulfan, lindane and aphidan. Out of these carbaryl, endosulfan, lindane and aphidan insecticides were effective against aphids and relatively safer to *C. septempunctata*.

Patel (1985) observed that malathion was found to be the most toxic insecticide to third instar grubs and adults of *M. sexmaculatus*, whereas both the stages of predator were comparatively less susceptible to demeton-o-methyl (0.05%). The order of toxicity to the third instar grubs was as malathion = dichlorvos > carbaryl > quinalphos > fenitrothion > endosulfan > monocrotophos > dimethoate > chlorpyriphos > phosphamidon > demeton-o- methyl. Similarly, the order of toxicity to the adults was as malathion = dichlorvos = carbaryl > fenitrothion > quinalphos > endosulfan > monocrotophos > chlorpyriphos > phosphamidon > demeton-o-methyl.

The comparative toxicity of various systemic insecticides was assessed against *C. septempunctata*. Thiometon spray against the sucking pests of groundnut was found to be significantly safer to the predator followed by oxydemeton methyl. Malathion was highly toxic to predator. The comparative toxicity of insecticides to predator in ascending order was, thiometon > oxydemeton methyl > phosphamidon > monocrotophos > dimethoate > malathion (Upadhyay and Vyas, 1986).

Zala (1995) studied the toxicity of certain insecticides to immature stages of *M. sexmaculatus* and revealed that quinalphos and triazophos 35 % + deltamethrin 1 % were found to be highly toxic to eggs, whereas quinalphos, phosphamidon and demeton-o-methyl were highly toxic to larvae. Endosulfan and fenvalerate were observed moderately toxic to eggs and larvae of *M. sexmaculatus*.

Zanwar and Jadhav (1997) assessed toxicity of seven insecticides on predator, *C. septempunctata*. The results concluded that endosulfan was found comparatively less toxic to the beetles than other insecticides tested. Higher mortality was recorded in all the insecticides after 12 hrs. than in 4 and 8 hrs. after treatment. Methidathion and quinalphos insecticides even at 0.03 per cent concentration found highly toxic to the predatory beetles than other insecticides. It was observed that there was 100 per cent mortality in trizophos, methidathion and quinalphos after 12 hrs. of the treatment.

Dhingra (1999) analyzed the safety margin of twenty four insecticides by bioassay techniques for the adults of aphid predator, *C. septempunctata*. On the basis of LC_{50}, the relative toxicity of different insecticides in the descending order was lambdacyhalothrin, decamethrin, alphamethrin, dimethoate, cypermethrin, monocrotophos, phosphamidon, fenitrothion, fenpropathrin, methyl parathion, dichlorvos, malathion, carbaryl, profenofos 40 % + cypermethrin 4 %, fenvalerate, quinalphos, profenophos, pyrethrin, trebon and methyl demeton. However, the less toxic insecticides were lindane, endosulfan, aphidan and menazon. The comparison of relative resistance value of adults of *C. septempunctata* vis-a-vis important aphid pests *viz.*; *L. erysimi, Dactynotus carthami* (Hille Ris Lambers)*, A. craccivora* and *M. persicae* indicated that out of the various insecticides tested methyl demeton, lindane, endosulfan and aphidan exhibited a very high safety margin for the predatory adults.

Rathod and Bapodra (2002) investigated the comparative toxicity of various systemic insecticides against predatory coccinellids associated with aphids in cotton. The endosulfan and dimethoate were found to be significantly safer to the coccinellids followed by oxy-demeton methyl, monocrotophos and phosalone. Polytrin and phosphamidon were comparatively more toxic to both the stages of coccinellid predator. The comparative toxicity to coccinellids in ascending order was endosulfan > dimethoate > oxydemeton methyl > monocrotophos > phosalone > quinalphos >profenophos > methyl parathion > imidacloprid > phosphamidon > polytrin.

Raguraman and Uthamasamy (2005) reported that spinosad was safe to natural enemies like*, Trichogramma chilonis* (Ishii)*, C. sexmaculata*, *Chrysoperla carnea* (Stephens) and *Argiope catenulate* (Doleschall) under laboratory by both contact and feeding toxicity tests.

Bhatt (2005) evaluated the relative toxicity of different insecticides against *M. sexmaculaus* and found that dimethoate 0.03 per cent was highly toxic to larvae and adults, while imidacloprid was least toxic to both the stages.

Bandral (2006) investigated field-weathered toxicity of insecticides on rapeseed leaves to aphid predator, *C. septempunctata* at different intervals after spray. At the recommended concentrations, higher mortality of predator was observed with cypermethrin and malathion than dimethoate and methyl demeton up to 3 days after spraying. On the 7th day after spray, residues of cypermethrin and malathion did not cause any mortality to the predator. On the 15th day after spray, all the insecticides did not cause any mortality to the predator except dimethoate which resulted in 6.67 per cent mortality during the 2nd year. The descending order of toxicity to the adult predator was dimethoate > methyl-o-demeton > cypermethrin > malathion.

Tank (2006) tested the relative toxicity of commonly used insecticides against eggs of *C. sexmaculata* and revealed that dichlorvos found to be most toxic, while acetamiprid and endosulfan proved safer insecticides. Larvicidal action of different insecticides revealed that dichlorvos, cypermethrin and fenvalerate caused significantly high mortality, however acetamiprid and endosulfan proved to be safer insecticides. Among the various insecticides evaluated, dichlorvos ranked first in their toxic action whereas acetamiprid and endosulfan proved less toxic to the adults of *C. sexmaculata*. Monocrotophos, phosphamidon, methyl-o-demeton, dimethoate, quinalphos, fenvalerate and cypermethrin found moderately to highly toxic to the adults.

Basappa (2007) estimated the toxicity of synthetic insecticides like imidacloprid, acetamiprid, thiomethoxam, profenophos and carbosulfan and compared with monocrotophos for their toxicity to *T. chilonis* and *C. sexmaculata*. Among six insecticides tested, carbosulfan found to be highly toxic to both species followed by acetamiprid. Imidacloprid was relatively less toxic to both the species.

Solangi *et al.* (2007b) evaluated the toxic effect of eight insecticides namely imidachloprid, biphenthrin, fenvalerate, diafenthiuron, fenpropathrin, indoxacarb, spinosad and emamectin benzoate at uniform dose of 2 ml in different concentrations against fourth instar grubs of *C. septumpunctata*. It was observed that all the insecticides caused higher mortality to the fourth instar grubs when applied at high concentration *i.e*., 2 ml/lit. of water. However, fenpropathrin was found comparatively more toxic with 72 and 90 % mortality at 96 hrs. and one week intervals, respectively. While spinosad was less toxic with 30 and 38 % mortality at 96 hrs. and one week intervals, respectively.

Jalali *et al.* (2009) reported that flonicamid and spinosad had no lethal effects on larvae and adults of *Adalia bipunctata* (Linnaeus). Imidacloprid was highly toxic to the larval stage by residual and ingestion exposure but caused very low adult mortality when ingested through contaminated prey. Dimethoate and lambda-cyhalothrin were highly toxic to both the larval and adult stages of the ladybird.

Meena and Kanwat (2010) tested the relative safety of pesticides against coccinellid beetles in okra ecosystem. Monocrotophos proved highly toxic followed by acephate whereas imidacloprid, endosulfan and endosulfan + *Bt* were moderately toxic to the coccinellid predators in okra.

Chakraborty (2012) evaluated few insecticides for their relative toxicity and indicated that significantly highest egg-mortality was found in emamectin benzoate considered as most toxic chemical to eggs, while clothianidin showed significantly least (12.98%) mortality over rest of the other insecticides. Buprofezin and thiamethoxam proved relatively less toxic to grubs of *C. sexmaculata* as these insecticides registered less than 70 % mortality. Clothianidin and imidacloprid showed 81.07 and 85.82 % mortality, respectively and considered as moderately toxic, whereas indoxacarb, emamectin benzoate and thiamethoxam registered more than 90 % mortality and proved most toxic to coccinellid grubs. Out of seven insecticides tested for their relative toxicity to adults of the predator, indoxacarb proved most toxic by showing more than 90 % adult mortality followed by thiamethoxam (83.74%). Buprofezin, clothianidin and emamectin benzoate proved moderately toxic to adults of *C. sexmaculata* wherein they registered 67.61 to 71.56 % mortality.

Pirasanna *et al.* (2012) tested the toxicity of insecticides at different concentrations against *C. sexmaculata*. Among them, acetamiprid showed highly toxic to grubs of *C. sexmaculata*, followed by thiamethoxam, imidacloprid, buprofezin and neembaan. Imidacloprid showed 14.8 times more toxic in comparison to buprofezin, whereas neembaan produced less than 50 % mortality irrespective of the concentration tested. Field recommended dose of imidacloprid recorded 26, 32 and 36 % mortality at 24, 48, 72 hrs. after treatment, respectively. However, field recommended dosage of acetamiprid and thiamethoxam caused almost 50% mortality. Whereas, buprofezin at recommended dose was considered to be safer, because it produced 10, 16, and 22 % mortality at 24, 48, and 72 hrs., respectively under laboratory conditions.

Awasthi *et al.* (2013) evaluated relative toxicity of six insecticides, *viz.*; spinosad, indoxacarb, emamectin benzoate, acephate, acetamiprid and imidacloprid against cotton aphid *A. gossypii* and different stages of predatory coccinellids. On the basis of LC_{50} values, acetamiprid was the most toxic whereas spinosad was the least toxic insecticide to cotton aphid. The order of relative toxicity of insecticides over spinosad was acetamiprid > acephate > imidacloprid > emamectin benzoate > indoxacarb, with their relative toxicity values being 82.28, 23.04, 16.18, 1.57 and 1.45 %, respectively. On the basis of LC_{50} values, spinosad was the safest insecticide for the different stages of the predatory coccinellids and acetamiprid was the most toxic followed by imidacloprid, indoxacarb, emamectin benzoate and acephate.

Khan *et al.* (2015) studied the toxicity of four commonly used insecticides, cypermethrin, emamectin benzoate, spinosad, and neem oil against different stages of *M. sexmaculatus*. The results showed that among the selected insecticides, cypermethrin exhibited high level of toxicity by causing maximum eggs, larvae, pupae, and adults (66.67, 83.33, 76.67 & 86%, respectively) mortality. Emamectin benzoate proved to be the best one with significantly least level of toxicity against eggs, larvae, pupae, and adults (26.67, 20, 20, & 30%, respectively) mortality. Spinosad followed Emamectin benzoate in toxicity against different stages of *M. sexmaculatus* (46.67, 50, 40, & 44%, respectively) mortality. The results further revealed that Neem oil was highly toxic by causing maximum eggs and pupal (80 & 86.67%, respectively) mortality. Thus, results showed that there was a potential to use emamectin benzoate in an IPM program.

Nag *et al.* (2017) experimented on the effect of conventional insecticides *viz.*; dimethoate, imidacloprid, thiamethoxam and thiacloprid and revealed that the effect of imidacloprid on ladybird beetles showed least detrimental effect followed by thiacloprid and thiamethoxam.

Shinde and Radadia (2017) studied the field persistence toxicity of various insecticides on larval and adult stages of *C. sexmaculata*. Among the different insecticides tested novaluron and profenophos grouped as extremely harmful to the adult stage. Imidacloprid and thiomethoxam were comparatively harmless to slightly harmful against both the stages. It was also observed that the adult stage was more prone to toxicity of insecticides as compared to larval stage.

Sanghani *et al.* (2018) gauged toxicity of thirteen insecticides against different stages of predatory coccinellid, *C. sexmaculata* and revealed that indoxacarb was highly toxic at 72 hrs. after treatment against eggs, whereas in case of grubs and adults, indoxacarb and methyl parathion were found highly toxic at 72 hrs. after treatment. Buprofezin caused the lowest mortality at 24, 48 and 72 hrs. after treatment, of all stages tested, hence can be considered as safer insecticide.

Sheela and Shinde (2019) tested the relative toxicity of spotted ladybird beetle under laboratory conditions to find out the safer insecticides to the predator. Study on relative toxicity of different insecticides against adults of the predatory beetle revealed that there were no insecticides under testing found highly toxic to the adults while, the treatment of novaluron was slightly harmful to the adults. Moreover, clothianidin, diafenthiuron, acetamiprid, spinosad, imidacloprid, thiamethoxam, flonicamid and dinotefuran found to be harmless to the adults. The treatment of control exhibited nil adult mortality.

3. MATERIALS AND METHODS

Present investigations on life table parameters, feeding potential and relative toxicity of various insecticides against *Cheilomenes sexmaculata* (Fabricius) were carried out at the laboratory of Department of Agricultural Entomology, B. A. College of Agriculture, Anand Agricultural University, Anand during the year 2019-20. The materials used and methodology adopted for the investigations on different aspects of *C. sexmaculata* are described here under different sub-headings.

3.1 Laboratory culture of *C. sexmaculata*

Initial culture of predatory coccinellid was collected from different field crops and maintained on their host (aphids). The methodology adopted here for rearing of *C. sexamaculata* on aphids was described by Tank (2006). The field collected adults were confined in a plastic jar (20.0×10.0 cm) covered with black muslin cloth and tightened with rubber band. The adults were provided with suitable number of aphids as food. Initially counted numbers of 15 to 20 aphids were provided, but with the gradual development of larvae the numbers of aphids were increased proportionally. Eggs laid by the female coccinellids on leaves or periphery of the jar was collected after 2 to 3 days, by gently brushing with a soft camel hair brush and were kept in plastic vials of 5.0 × 4.0 cm size, with paper pieces to minimize cannibalism among emerging grubs. Initially the newly hatched grubs were reared in groups for two days in plastic jar and then reared individually in plastic vials. Nymphs of aphids (upto 100) were provided daily to each individual in plastic vials to the predatory grubs until pupation. The adults emerged out from pupae were collected individually with the help of plastic tube and transferred to an aluminum cage of size 15.0 × 15.0 × 15.0 cm for mating (Plate I). Newly emerged adults were provided with host (prey) as described earlier. The culture of the predator maintained by above described method was used for further study of different parameters.

3.2. Construction of life table of *C. sexmaculata*

3.2.1. Rearing of *C. sexmaculata*

For constructing the life table, the culture of *C. sexmaculata* was maintained as mentioned above, for two consecutive generations at constant temperature of 25 ± 1 °C using B.O.D. incubator. Freshly laid 100 eggs were collected from the cage with the help of wet camel hair brush and placed in 10 Petri dishes in batches of 10 each (Plate II). The eggs were placed on the slides in one row to facilitate observations on hatching. Fresh food was provided daily in the morning. Observations on hatching, total larval development, formation of pupae, emergence of adults and fecundity of females were recorded daily. Age specific mortality in different developmental stages such as eggs, larvae, pupae and adults were recorded. With a view to determine the age specific fecundity, total number of adults emerged on the same day were kept separately in oviposition cage for oviposition. Numbers of eggs laid on subsequent days were recorded. The observations on fecundity were continued till all the females died. The female birth was calculated according to the sex ratio. Life tables were constructed according to the methods of Birch (1948), Howe (1953) and Atwal and Bains (1974).

3.2.2. Sex separation

The female tends to be larger than the males (Plate III). In males, the distal margin of seventh abdominal sternite was concave in shape, while in female they were convex. Male ladybird beetles display lighter pigmentation of their labrums and prosternums, while females had darker pigmentation (Doston, 2018).

3.2.3. Life table of *C. sexmaculata*

Stable age distribution was worked out by observing the population schedule of birth rate and death rate (m_x and l_x) when grown in limited spare. Life expectancy was computed by using the method suggested by Deevey (1947) and Atwal and Bains (1974).

The column headings for construction of life fecundity tables proposed by Birch (1948), Howe (1953) and Atwal and Bains (1974) were used in this study. The same are as under.

x = Pivotal age in days

l_x = Survival of female at age ‘x’

m_x = Age schedule for female birth at age ‘x’

3.2.3.1 Net reproductive rate

The value of ‘x’, ‘l_x’ and ‘m_x’ was calculated from the data given in life tables. The sum total of products ‘$l_x m_x$’ is the net reproductive rate (R_O) (Lotka, 1926). The ‘R_O’ is the rate of multiplication of population in generation measured in terms of number of females produced per generation. The number of times a population would multiply per generation was calculated by using the following formula:

$$R_0 = \Sigma\, l_x m_x$$

3.2.3.2 Mean duration of generation (T_C)

The approximate rate of generation time (T_C) (the mean age of the mothers in a cohort at the birth of female off-spring) was calculated with the help of following formula:

$$T_c = \frac{\Sigma\, x l_x m_x}{R_0}$$

3.2.3.3 Innate capacity for increase in numbers (r_m)

Total numbers of individuals survived and mean number of female offsprings birth were recorded at each age interval. From these data the arbitrary values of ‘r_m’ were derived by using the following formula.

$$r_m = \frac{\ln_e R_0}{T_c}$$

Where,

e = 2.71828

T_c = Mean generation time

The intrinsic rate of increase (r_m) was calculated from the arbitrary 'r_m' by taking three trial values arbitrarily selected on either side of it differing in the second decimal place by establishing the following relationship (Atwal and Bains, 1974).

$$\sum e^{7-r_m x} . l_x m_x = e^7 = 1097$$

Such tables were constructed with the help of 'x' and '$l_x m_x$' for each trial of 'r_m'. The values of $\sum e^{7-r_m x} . l_x m_x$ obtained from the trial and it was plotted against their arbitrary 'r_m', which gave a straight line. The straight line was intersected by a vertical line drawn from the described values of $\Sigma\ e^{7-r_m x} . l_x m_x = 1097$. The point of the intersection gave a value of true 'r_m' accurate to four decimal points. The precise generation time (T) was then calculated by using following formula:

$$x = \frac{l\iota \quad {}_e R_0}{r_m}$$

3.2.3.4. The finite rate of natural increase (λ)

The number of females per female per day *i.e.* finite rate of increase was determined by:

$$\lambda = a \quad l\iota \quad {}_e{}^{r_m}$$

From these data, the weekly multiplication of the population was calculated. Hypothetical F_2 females were worked out with formula $(R_o)^2$ from net reproductive rate R_0 as calculated in 3.2.3.1.

3.2.3.5. Stable age distribution

The stable age distribution (per cent distribution of various age groups) of the *C. sexmaculata* was worked out with the knowledge of 'r_m' and the age specific mortality of the immature and mature stages. The stable age distribution table was constructed by following the method of Andrewartha and Birch (1954) and Atwal and Bains (1974). The 'L_x' (life table age distribution) was calculated from the 'l_x' by using the following formula:

$$L_x = \frac{l_x + l_{(x+1)}}{2}$$

Per cent distribution of each age group was calculated by multiplying the L_x with $e^{-r_m(x+1)}$. By putting together the percentage under each stage *viz.*; egg, larval, pupal and adult stages, the expected per cent distribution was worked out.

3.2.3.6. Life expectancy

Life expectancy was worked out by using columns x, l_x, d_x, 100 q_x, L_x, T_x and e_x.

Where,

x = Pivotal age (days)

l_x = Number of surviving at the beginning of age interval out of 100

d_x = Number dying during 'x'

$100\ q_x = \frac{d_x \times 1}{l_x}$, mortality rate per hundred alive at beginning of age interval

$L_x = \frac{l_x + l_{(x+1)}}{2}$, Alive between age x and x + 1

T_x = Number of individual's life days beyond 'x'

$e_x = \frac{T_x}{l_x} \times 2$ Expectation of further life

3.3. Feeding potential of *C. sexmaculata* on different species of aphids

3.3.1. Details of experiment:

Location : Department of Agricultural Entomology, BACA, AAU, Anand

Design : Completely Randomized Design

Treatments (hosts) : 4 (Aphids : mustard aphid, *Lipaphis erysimi*, cotton aphid, *Aphis gossypii*, maize aphid, *Rhopalosiphum maidis* and cowpea aphid, *Aphis craccivora*)

Repetitions : 5

Year : 2019-20

3.3.2. Methodology

To insight the knowledge of feeding potential, a laboratory study was carried out. For this, total 15 grubs of *C. sexmaculata* were reared individually on different species of aphids *viz.*; mustard aphid, *L. erysimi*, cotton aphid, *A. gossypii*, maize aphid, *R. maidis* and cowpea aphid, *A. craccivora* in plastic vials (5.0×4.0 cm) right from first day of hatching from eggs to the formation of pupae (Plate IV). Initially counted numbers of 15 to 20 aphids were provided, but with the gradual development of larvae the numbers of aphids were increased proportionally. The numbers of aphids consumed by individual larva were recorded daily. The feeding potential was worked out for individual instar as well as for entire larval period. The newly emerged adults of *C. sexmaculata* were kept individually in plastic bottle (6.5×6.0 cm) and each adult was provided with 100 aphids daily during entire adult period and the feeding capacity of adult was worked out. Numbers of aphids consumed by individual by ladybird beetle at different stages of larva and adult were recorded daily.

3.4. Relative toxicity of some insecticides to *C. sexmaculata* under laboratory conditions

A laboratory study was conducted to determine the relative toxicity of some insecticides against eggs, grubs and adults of *C. sexmaculata*. The insecticides (Plate V) were evaluated for their ovicidal, larvicidal as well as adulticidal action. The ovicidal toxicity was evaluated by egg-dipping method. Susceptibility of grubs towards different insecticides was evaluated by dry film method whereas for grubs and adults, it was evaluated by topical application method. Mortality of respective life-stages was recorded at 24, 48 and 72 hrs. after treatment.

3.4.1. Details of experiment:

Location	:	Department of Agricultural Entomology, BACA, AAU, Anand
Design	:	Completely Randomized Design
Treatments	:	10
Repetitions	:	3
Year	:	2019-20

Table 3.1. Details of insecticides used to determine their relative toxicity to *C. sexmaculata*

Technical name	Conc. (%)	Dose (g or ml/lit. of water)	Source
Acetamiprid 20 SP	0.006	0.3	BASF (India) Ltd., Mumbai
Buprofezin 25 SC	0.05	2.0	Dhanuka Agritech Ltd.,Ahmedabad
Fipronil 5 SC	0.01	2.0	Bayer Crop Science (India) Ltd., Mumbai
Flonicamid 50 WG	0.015	0.3	UPL Ltd., Mumbai
Imidacloprid 17.8 SL	0.0089	0.5	Bayer Crop Science (India) Ltd., Mumbai
Spinosad 45 SC	0.0135	0.3	Dow Agrosciences India Private Ltd., Ahmedabad
Spiromesifen 22.9 SC	0.0229	1.0	Bayer Crop Science (India) Ltd., Mumbai
Thiacloprid 21.7 SL	0.013	0.6	Bayer Crop Science (India) Ltd., Mumbai
Thiamethoxam 25 WG	0.01	0.4	Syngenta India Ltd., Ahmedabad
Water (control)	-	-	

3.4.2. Method for application of insecticides

3.4.2.1. Ovicidal toxicity:

Three sets consisting of 10 eggs in each were taken for each insecticidal treatment. A set of two days old 10 eggs in each was delicately dipped for about one minute in the spray fluid of respective insecticide and then taken out, air dried and kept in individual plastic vials (4.5×3.5 cm). Eggs dipped in water were kept as control (check). Treated eggs were observed daily till all the eggs hatch out in control treatment (up to 5 days).

3.4.2.2. Dry film method

Plastic vials were used for the experiment. Such plastic vials and inner side of its lid were sprayed with respective insecticidal solution and air-dried under fan for about 15 to 20 minutes. Grubs of *C. sexmaculata* were exposed to the surface residue of insecticide inside the plastic vials. Aphids (15 to 20) were provided to the predatory grubs as food and food was changed daily in the morning. The mortality percentage was worked out by following Abbott’s formula (Abbott, 1925).

$$\mathbf{P} = \frac{\mathbf{P}\quad -\mathbf{C}}{\mathbf{1}\quad -\mathbf{C}} \times \mathbf{100}$$

Where,

P = Corrected per cent mortality

P1= Observed per cent mortality in treatment

C = Per cent mortality in control

3.4.2.3. Topical application

A set of 10 second instar (4 days old) grubs of predatory coccinellid were kept in glass Petri dish (7.5×2.5 cm) and topically sprayed with respective insecticidal spray fluid by using hand atomizer with fine mist spray. The treated grubs were then transferred individually into plastic vials, provided with nymphs of aphids as food and covered with lid. Each treatment was replicated thrice. Food was provided daily in the morning and per cent mortality was worked out by following Abbott’s formula (Abbott, 1925) as mentioned in 3.4.2.2.

3.4.3. Observations recorded

Numbers of dead individuals were recorded and mortality percentage was worked out of respective life-stages at 24, 48 and 72 hrs. after treatments.

3.5. Compilation and statistical analysis of data

The data recorded on various parameters were compiled and analyzed as per the ANOVA technique following appropriate transformation as suggested by Steel and Torrie (1980).

4. RESULTS AND DISCUSSION

The results pertaining to the investigation on life table and feeding potential of *Cheilomenes sexmaculata* (Fabricius) against four different species of aphids and relative toxicity of different insecticides to this predator have been described under different headings and discussed with relevant review in this chapter.

4.1. Life table of *C. sexmaculata* under laboratory conditions

The studies on life table, age specific distribution and life expectancy of *C. sexmaculata* on *A. gossypii* were carried out at Department of Agricultural Entomology, Anand Agricultural University, Anand at a constant temperature of 25 ± 1 ^{0}C during the month of November 2019 to Febuary 2020. The results obtained are presented herewith.

An attempt was made to work out the number of individuals survived during development. The data (Table 4.1) indicated that there was very less mortality during egg stage. The numbers that survived from 100 eggs to adult emergence was 98 individuals. The maximum duration of egg stage, larval stage, pre pupal stage and pupal stage were recorded as 2, 9, 2 and 4 days, respectively.

Life fecundity table was constructed to determine the survival of female (l_x) and age specific fecundity (m_x). Close interpretation of the data (Tables 4.2 and 4.3 depicted in figure 4.1) indicated that pre-oviposition period was between 18th and 21st days of pivotal age. Female started laying eggs after 22th day and ceased after 35th day with l_x values being 0.82 and 0.01, respectively. The females contributed the highest number of progeny (m_x = 28.82) on 27th day of pivotal age, which decreased day by day.

The net reproductive rate (R_0) of 129.47 (Table 4.3) was obtained with mean length of generation (T) at 26.81 days. The intrinsic rate of natural increase in numbers (r_m) was 0.1871 females per female per day and the population would be able to multiply 3.7034 times a week. The hypothetical F_2 females were worked out to

Table 4.1. Survival of different life stages of *C. sexmaculata*

Sr. No.	**No. of eggs**	**Number of individuals survived**			
		Egg stage (0–2 days)	**Larval stage** (3–11 days)	**Pre-pupal stage** (12-13 days)	**Pupal stage** (14–17 days)
1	10	10	10	10	10
2	10	10	9	9	9
3	10	10	9	9	8
4	10	10	9	9	9
5	10	9	8	8	7
6	10	10	10	10	9
7	10	10	8	8	8
8	10	10	9	9	9
9	10	9	6	6	6
10	10	10	10	10	10
Total	**100**	**98**	**88**	**88**	**85**

Table 4.2. Life table and age specific fecundity of *C. sexmaculata* (for female)

Pivotal age in days (x)	Survival of female at different age interval (l_x)	Age schedule for female births (m_x)	$l_x m_x$	$x l_x m_x$
0-17	**Immature stages**			
18-21	**Pre-oviposition period**			
22	0.82	4.76	3.90	85.89
23	0.82	9.91	8.13	186.96
24	0.81	15.90	12.88	309.14
25	0.75	21.73	16.30	407.40
26	0.75	24.99	18.74	487.29
27	0.70	28.82	20.17	544.61
28	0.69	22.70	15.66	438.48
29	0.60	22.08	13.25	384.12
30	0.55	19.53	10.74	322.29
31	0.41	15.05	6.17	191.34
32	0.30	8.83	2.65	84.73
33	0.14	5.62	0.79	25.96
34	0.04	2.33	0.09	3.16
35	0.01	0.41	0.00	0.14
			$\Sigma l_x m_x$ =129.47	$\Sigma x l_x m_x$ =3471.52

Table 4.3. Mean length of generation, innate capacity for increase in numbers and finite rate of increase in numbers of *C. sexmaculata*

Sr. No.	Population growth statistics	Formula	Calculated values
1	**Net reproductive rate**	$R_0 = \Sigma l_x m_x$	129.47
2	**Mean length of generation (days)**	$T_c = \frac{\Sigma\ l_x m_x}{R_0}$	26.81
3	**Innate capacity for increase in numbers (Females/female/day)**	$r_m = \frac{li\ {}_e R_0}{T_c}$	0.1814
4	**Arbitrary 'r_m' (r_c) = 0.18 and 0.19**	-	-
5	**Corrected 'r_m' (Females/female/day)**	$\sum e^{7-r_m x} . l_x m_x$	0.1871
6	**Corrected generation time (days)**	$T = \frac{li\ {}_e R_0}{r_m}$	26.00
7	**Finite rate of increase in numbers (Females/female/day)**	$\lambda = a \quad li\ {}_e{}^{r_m}$	1.2057
8	**Weekly multiplication of population (times)**	$(\lambda)^7$	3.7034
9	**Hypothetical F_2 females**	$(R_0)^2$	16763.69

Table 4.4. Age specific distribution of *C. sexmaculata* (r_m = 0.1817)

Pivotal age in days (x)	Survival of female at different age interval (l_x)	$e^{-r_m(x+1)}$.	l_x. $e^{-r_m(x+1)}$	Per cent distribution
0	1.00	0.8294	0.8294	17.9027
1	1.00	0.6879	0.6879	14.8481
2	0.98	0.5705	0.5591	12.0683
Total				**44.8191**
3	0.98	0.4732	0.4637	10.0092
4	0.98	0.3924	0.3846	8.3014
5	0.96	0.3255	0.3125	6.7445
6	0.93	0.2699	0.2510	5.4189
7	0.91	0.2239	0.2037	4.3977
8	0.91	0.1857	0.1690	3.6473
9	0.90	0.1540	0.1386	2.9918
10	0.88	0.1277	0.1124	2.4262
11	0.88	0.1059	0.0932	2.0122
Total				**45.9491**
12	0.88	0.0879	0.0773	1.6689
13	0.88	0.0729	0.0641	1.3841
Total				**3.0530**
14	0.87	0.0604	0.0526	1.1349
15	0.87	0.0501	0.0436	0.9413
16	0.85	0.0416	0.0353	0.7627
17	0.85	0.0345	0.0293	0.6326
Total				**3.4715**

Continue……

Pivotal age in days ‘x’	**Survival of female at different age interval (l_x)**	$e^{-r_m(x+1)}$.	l_x. $e^{-r_m(x+1)}$	**Per cent distribution**
18	0.85	0.0286	0.0243	0.5247
19	0.84	0.0237	0.0199	0.4300
20	0.84	0.0197	0.0165	0.3566
21	0.84	0.0163	0.0137	0.2958
22	0.82	0.0135	0.0111	0.2395
23	0.82	0.0112	0.0092	0.1986
24	0.81	0.0093	0.0075	0.1627
25	0.75	0.0077	0.0058	0.1250
26	0.75	0.0064	0.0048	0.1036
27	0.70	0.0053	0.0037	0.0802
28	0.69	0.0044	0.0030	0.0656
29	0.60	0.0037	0.0022	0.0473
30	0.55	0.0030	0.0017	0.0360
31	0.41	0.0025	0.0010	0.0222
32	0.30	0.0021	0.0006	0.0135
33	0.14	0.0017	0.0002	0.0052
34	0.04	0.0014	0.0001	0.0012
35	0.01	0.0012	0.0000	0.0003
			Total	**2.7081**

Table 4.5. Life table for computing life expectancy of *C. sexmculata*

Pivotal age in days	Number surviving to the beginning of age interval	Number dying during 'x'	Mortality rate per hundred alive at beginning of age interval $\frac{d_x \times 1}{l_x}$	Alive between age 'x'and 'x + 1' $\frac{l_x + l_{(x+1)}}{2}$	No. of the individual's life days beyond 'x'	Expectation of further life $\frac{T_x}{l_x} \times 2$
(x)	**(l_x)**	**(d_x)**	**(100 q_x)**	**(L_x)**	**(T_x)**	**(e_x)**
0-5	100	4	4.00	98	535.00	10.70
5-10	96	8	8.33	92	437.00	9.10
10-15	88	1	1.14	87.5	345.00	7.84
15-20	87	3	3.45	85.5	257.50	5.92
20-25	84	9	10.71	79.5	172.00	4.09
25-30	75	20	26.67	65	92.50	2.47
30-35	55	55	100.00	27.5	27.50	1.00

be 16,763.69. No similar records are found for these observations, and hence comparisons are lacking. Although, Zhao *et al.* (2015) observed more or less similar results for *C. sexmaculata* on *A. craccivora* a few differences that are observed may be due to the difference in the host aphid species. Abbas *et al.* (2020) observed that intrinsic rate of increase (r_m) and mean length of generation time (T_c) of the life table of *M. sexmaculatus* against different aphid species. The results recorded on *Myzus persicae* and *Lipaphis erysimi* were somewhat similar to that found on present investigation. The net reproductive rate (R_0) recorded on host *Aphis nerii* was nearer to that observed on *A. gossypii* in present investigation.

In present investigation, the contribution of each developmental stage and the stable age distribution were also calculated (Table 4.4). The data showed that adults contributed only 2.7081 per cent to the population of stable age and that of eggs, larvae, pre-pupal and pupae was 44.81, 45.95, 3.053 and 3.471 %, respectively. These observations lack comparisons, since no similar observations pertaining to stable age distributions parameters were available.

The life expectancy data (Table 4.5) clearly indicated that life expectancy of *C. sexmaculata* declined gradually with the advancement of development. The life expectancy of newly deposited eggs was 10.70 days. The expectancy of further life was 5.92 days at the time of adult emergence. The life expectancy of *A. nerii* and *M. persicae* recorded by Abbas *et al.* (2020) which is somewhat similar to the present findings of investigations.

4.2. Feeding potential of *C. sexmaculata* on different aphid species

In order to determine the relative feeding potential of *C. sexmaculata* on four different species of aphids, *viz;* cotton aphid, *A. gossypii*, bean aphid, *A. craccivora*, maize aphid, *R. maidis* and mustard aphid, *L. erysimi* were recorded separately under laboratory conditions.

Data on consumption capacity of *C. sexmaculata* on four different species of aphids are presented in Table 4.6. It revealed that significantly highest (20.13±0.61) numbers of *A. craccivora* individuals were consumed by first instar grubs of

C. sexmaculata closely followed by *A. gossypii* (20±0.67) and preferred more over *R. maidis* and *L. erysimi*. First instar grub consumed an average of 10.67 ± 0.53 and 9.6 ± 0.89 individuals of *R. maidis* and *L. erysimi* respectively. In case of second instar grub, a highest number of individuals consumed were of *R. maidis* (35.27±0.49), followed by *A. gossypii* (33.97±0.91) and *A. craccivora* (32.93±3.80), but significantly less consumption was found with *L. erysimi* (19.93±0.64). Highest (57.87±2.81) numbers of *A. gossypii* were consumed by the third instar grub of *C. sexmaculata* followed by *A. craccivora* (56.03±1.58). Significantly more numbers of *A. gossypii* individuals were predated by third instar grubs than *R. maidis* (52.40±1.34) and *L. erysimi* (31.37±1.81).

The fourth instar grub showed the same trend of feeding preference as per third instar grubs on *A. gossypii* and *A. craccivora*. Maximum numbers of *A. gossypii* (79.60±1.99) were fed by fourth instar than rest of the three species of aphids. *Aphis craccivora* (68.00±2.83) stood next to *A. gossypii* in preference. The minimum feeding by fourth instar grubs was observed in *L. erysimi* (44.83±2.51). Total number of aphids consumed during entire grub period was varied from 105.73 to 191.20. Maximum (191.20±4.17) numbers of *A. gossypii* were fed by the grubs of *C. sexmaculata* followed by *A. craccivora* (177.10±5.48), *R. maidis* (161.83±4.26) and *L. erysimi* (105.73±3.83). The grubs consumed significantly more number of individuals of *A. gossypii* and *A. craccivora* over *R. maidis* and *L. erysimi*.

Data (Table 4.6) on biotic potential of *C. sexmaculata* adults revealed that significantly maximum (820.30 ± 44.94) numbers of *A. craccivora* were eaten by the individual beetle than rest of the aphid species. The adult consumed an average of 739.93 ± 28.96, 576.23 ± 23.43 and 441.33 ± 40.35 individuals of *A. gossypii*, *R. maidis* and *L. erysimi*, respectively. Total consumption of aphids by both the feeding stages (grub and adult) of *C. sexmaculata* varied from 547.07 to 997.40. Significantly highest (997.40±45.60) numbers of *A. craccivora* individuals were consumed by the predator than individuals of other species of aphids. *Aphis gossypii* (930.67±55.59) was also found to be a preferred host for *C. sexmaculata* next to *A. craccivora*. The predator consumed 738.06 ± 22.87 individuals of *R. maidis* during its entire life. *Lipaphis erysimi* proved less preferred host for *C. sexmaculata* as 547.07 ± 42.91 individuals were eaten by the predator. The data revealed that feeding efficacy of *C. sexmaculata* adults was higher than that of larvae (figure 4.2). This is further confirmed by Priyadarshani *et al.* (2016) as they also observed that larvae consumed more aphids than adults.

The observations of present studies coincided with the results of the feeding potential of *C. sexmaculata* done by Zala (1995) on *L. erysimi* and Patel (1998) on *R. maidis.* Similarly, Solangi *et al.* (2007a) reported that *C. sexmaculata* grubs and adults were voracious feeders on corn leaf aphid, *R. maidis*, cotton aphid, *A. gossypii* and alfalfa aphid, *T. trifolii*. The third and fourth instars grubs consumed more prey per day than first and second instars. Further, Pirasanna *et al.* (2012) also recorded more or less similar results. They found that fourth instar grubs consumed significantly more aphids when compared to first, second and third instars. The per day predation rate by female ladybird beetle on *A. craccivora* was 37.2 ± 3.32, followed by *A. gossypii* (35.2±2.22) and *L. erysimi* (23±0.94). The male could feed only on *A. craccivora* (35.8±2.67) followed by *A. gossypii* (30.8±1.98), *R. maidis* (27.8±4.28) and *L. erysimi* (20.8±1.15). Also, Vasista (2019) revealed that beetle prefer *A. craccivora* the most followed by *A. gossypii.*

From above results it is observed that among the four different species of aphids, *L. erysimi* was preferred least by *C. sexmaculata* which is in close conformity with the results of Varma *et al.* (1983), Tank (2006) and Chakraborty (2012). Singh *et al.* (2012) also reported that mustard aphid, *L. erysimi* found least preferred host for *C. septempunctata* in laboratory.

Table 4.6. Feeding potential of *C. sexmaculata* on different species of aphids

Aphid species	**Mean no. of aphids consumed at different feeding stages**						**Mean no. of aphids consumed / individual**
	Grub					**Adult**	
	1st instar	**2nd instar**	**3rd instar**	**4th instar**	**Total**		
A. cracivvora	20.13 ± 0.61 (16-24)*	32.93 ± 3.80 (23-41)	56.03 ± 1.58 (52-62)	68.00 ± 2.83 (61-79)	177.10 ± 5.48 (167-188)	820.30 ± 44.94 (610-918)	997.40 ± 45.60 (792-1102)
A. gossypii	20 ± 0.67 (17-24)	33.97 ± 0.91 (29-40)	57.87 ± 2.81 (51-63)	79.60 ± 1.99 (72-90)	191.20 ± 4.17 (177-209)	739.93 ± 28.96 (523-888)	930.67 ± 55.59 (711-1085)
R. maidis	10.67 ± 0.53 (52-62)	35.27 ± 0.49 (32-39)	52.40 ± 1.34 (49-60)	63.50 ± 2.76 (51-69)	161.83 ± 4.26 (146-171)	576.23 ± 23.43 (472-643)	738.06 ± 22.87 (636-807)
L. erysimi	9.6 ± 0.89 (8-13)	19.93 ± 0.64 (12-24)	31.37 ± 1.81 (26-36)	44.83 ± 2.51 (40-56)	105.73 ± 3.83 (96-119)	441.33 ± 40.35 (251-579)	547.07 ± 42.91 (347-689)
S. Em. ±	0.49	1.41	1.24	1.80	2.95	26.01	26.64
C. V. (%)	4.55	6.54	3.56	3.98	2.63	5.71	4.67

* Figures in bracket indicate range values

4.3. Relative toxicity of insecticides against *C. sexmaculata*

4.3.1. Ovicidal action:

The data on corrected per cent mortality presented in Table 4.7 and depicted in figure 4.3 indicated that there was a significant difference among the insecticides. The toxicity of flonicamid, buprofezin and thiamethoxam showed significantly less toxic to other treatments. On the other hand eggs treated with flonicamid (10.36%) exhibited significantly relatively lower mortality over rest of the insecticides. The chronological order of toxicity of various insecticides based on egg mortality was acetamiprid (60.37%) > thiacloprid (53.52%) > spinosad (37.75%) > imidacloprid (31.77%) > spiromesifen (31.10%) > fipronil (22.37%) > thiamethoxam (20.73%) > buprofezin (18.86%) > flonicamid (10.36%). The highest (60.37%) mortality was found in acetamiprid followed by thiacloprid (53.52%). These findings closely matched with the findings of Basappa (2007), who concluded that among six insecticides tested, carbosulfan found to be highly toxic to *C. sexmaculata* followed by acetamiprid. Similar results were also obtained by Awasthi *et al.* (2013). However, in contrast to this, Chakraborty (2012) and Tank (2006) who reported that the acetamiprid was relatively safer to the eggs of *C. sexmaculata.* Such discrepancy in toxicity to eggs may be accounted for variations in concentration of insecticides or method of evaluation used while bioassay.

Table 4.7. Toxicity of various insecticidal treatments to eggs of *C. sexmaculata*

Sr. No.	Treatments	Corrected mortality (%)
1	Acetamiprid 20 SP (0.006%)	50.99a (60.37)**
2	Buprofezin 25 SC (0.05%)	25.74e (18.86)
3	Fipronil 5 SC (0.01%)	28.23e (22.37)
4	Flonicamid 50 WG (0.015%)	18.78f (10.36)
5	Imidacloprid 17.8 SL (0.0089%)	34.31cd (31.77)
6	Spinosad 45 SC (0.0135%)	37.91c (37.75)
7	Spiromesifen 22.9 SC (0.0229%)	33.90d (31.10)
8	Thiacloprid 21.7 SL (0.013%)	47.02b (53.52)
9	Thiamethoxam 25 WG (0.01%)	27.09e (20.73)
	S. Em. ±	0.79
	F test for treatment	Sig.
	C.V. (%)	4.08

Notes: 1) *Treatment means with common letter(s) are/is not significant at 5% level of significance by DNMRT
2) **Figures in the parentheses are re-transformed values and those outside are arc-sin transformed values

4.3.2. Larvicidal action:

The mortality of the grubs of *C. sexmaculata* to various insecticides was assessed by two methods *viz.*, dry film method and topical application method at 24, 48 and 72 hrs. The data on corrected per cent mortality of larval stage is mentioned in Table 4.8 & 4.9.

4.3.2.1. Dry film method:

Grub mortality at 24 hrs. after (Table 4.8) treatment revealed that among the different treatments evaluated, significantly least mortality was registered in flonicamid (0.02%). In terms of grub mortality buprofezin (10.36%) and thiamethoxam (10.36%) found to be at par with each other and exhibited significantly lower mortality than the treatment of fipronil (20.73%), imidacloprid (31.10%) and spiromesifen (31.10%). Maximum (51.85%) mortality was recorded in acetamiprid (51.85%) followed by thiacloprid (48.14%) and spinosad (41.47%).

Observations recorded at 48 hrs. after treatment indicated that acetamiprid (64.47%) found more toxic than other treatments. While thiacloprid (57.04%) and spinosad (53.71%) followed next to acetamiprid and were at par with each other. Imidacloprid (34.40%) and spiromesifen (32.21%) found to be moderately toxic and were non-significantly different in their results. Fipronil (28.51%) found at par with spiromesifen. While the effect of flonicamid (0.02%) found to be almost negligible on grubs mortality. Buprofezin followed next to flonicamid with 10.73 % mortality also found at par with thiamethoxam (17.75%).

Mortality of grubs of *C. sexmaculata* due to insecticidal treatments recorded at 72 hrs. after treatment showed that both the treatments of flonicamid (0.02%) and buprofezin (11.57%) exhibited significantly lower mortality of the predator in comparision to the other insecticides evaluated. Acetamiprid (88.43%) registered maximum mortality of *C. sexmaculata* and found at par with thiacloprid (86.66%). Spinosad (69.52%) was also found toxic to ladybird beetle larvae but significantly different from acetamiprid and thiacloprid.

Table 4.8. Impact of various insecticidal treatments on grubs of *C. sexmaculata* through dry film method

Sr. No.	Treatments	Corrected mortality (%) at indicated intervals (hrs.)		
		24	48	72
1	Acetamiprid 20 SP (0.006%)	46.06a (51.85)**	53.42a (64.47)	70.12a (88.43)
2	Buprofezin 25 SC (0.05%)	18.78e (10.36)	19.12e (10.73)	19.88f (11.57)
3	Fipronil 5 SC (0.01%)	27.09d (20.73)	32.28d (28.51)	40.60d (42.35)
4	Flonicamid 50 WG (0.015%)	0.91f (0.02)	0.91f (0.02)	0.91g (0.02)
5	Imidacloprid 17.8 SL (0.0089%)	33.89c (31.10)	35.68c (34.04)	49.54c (57.89)
6	Spinosad 45 SC (0.0135%)	40.09b (41.47)	47.13b (53.71)	56.49b (69.52)
7	Spiromesifen 22.9 SC (0.0229%)	33.89c (31.10)	34.58cd (32.21)	42.87d (46.29)
8	Thiacloprid 21.7 SL (0.013%)	43.94a (48.14)	49.05b (57.04)	68.58a (86.66)
9	Thiamethoxam 25 WG (0.01%)	18.78e (10.36)	24.92e (17.75)	28.75e (23.14)
	S. Em. ±	0.79	0.70	0.92
	F test for treatment	Sig.	Sig.	Sig.
	C.V. (%)	4.08	4.16	4.81

Notes: 1) *Treatment means with common letter(s) are/is not significant at 5% level of significance by DNMRT
2) **Figures in the parentheses are re-transformed values and those outside are arc-sin transformed values

4.3.2.2. Topical application method

Observations of grub mortality (Table 4.9) recorded at 24 hrs. after treatment revealed that significantly least (0.02%) mortality of *C. sexmaculata* grubs was registered in flonicamid than rest of insecticidal treatments. Highest mortality of grubs was found in acetamiprid (51.86%). Thiacloprid ranked second in position by exhibiting 41.47 % mortality followed by spinosad which showed 34.39 % mortality. Spinosad was also found at par with imidacloprid with 31.10 % mortality. With respect to grub mortality, spiromesifen (29.25%) and imidacloprid (31.30%) found to be at par and proved moderately toxic as compared to others. Next to spiromesifen stood fipronil showed 20.73 % mortality which was significantly different as compared to other treatments. Buprofezin and thiamethoxam (10.36%) registered significantly lesser toxic to the grubs in comparison to other insecticides.

Mortality data (Table 4.9) recorded at 48 hrs. after treatment indicated that acetamiprid exhibited maximum (65.56%) mortality followed by thiacloprid (60.37%). Among the insecticides evaluated significantly lower mortality of *C. sexmaculata* grubs were recorded in the treatment of flonicamid (10.02%) and buprofezin (10.36%). Both these treatments were significantly at par with each other. Thiacloprid found to be at par with spinosad (55.19%), while significantly different from acetamiprid. The result of spinosad was non-significantly different from imidacloprid (51.11%). Also spiromesifen (44.81%) was at par with imidacloprid, but was significantly different from spinosad.

The superiority of flonicamid (10.02%)and buprofezin (10.73%) to *C. sexmaculata* grubs for their safety was also noticed even at 72 hrs. after treatment. Both these treatments were at par with each other. Among the insecticides evaluated, acetamiprid showed significantly higher (99.19%) mortality. Acetamiprid was followed by thiacloprid, spinosad, imidacloprid, spiromesifen, and fipronil with 76.86, 74.90, 66.12, 51.86 and 42.95 %, respectively.

Table 4.9. Toxicity of various insecticidal treatments on grubs of *C. sexmaculata* through topical application method

Sr. No.	Treatments	Corrected mortality (%) at indicated intervals (hrs.)		
		24	48	72
1	Acetamiprid 20 SP (0.006%)	46.06a (51.86)**	54.07a (65.56)	84.85a (99.19)
2	Buprofezin 25 SC (0.05%)	18.77f (10.36)	18.78f (10.36)	19.12g (10.73)
3	Fipronil 5 SC (0.01%)	27.09e (20.73)	34.91d (32.76)	40.95e (42.95)
4	Flonicamid 50 WG (0.015%)	0.91g (0.02)	18.45f (10.02)	18.45g (10.02)
5	Imidacloprid 17.8 SL (0.0089%)	33.89cd (31.10)	45.64bc (51.11)	54.40c (66.12)
6	Spinosad 45 SC (0.0135%)	35.90c (34.39)	47.98b (55.19)	59.94b (74.90)
7	Spiromesifen 22.9 SC (0.0229%)	32.74d (29.25)	42.02c (44.81)	46.06d (51.86)
8	Thiacloprid 21.7 SL (0.013%)	40.09b (41.47)	50.99ab (60.37)	61.25b (76.86)
9	Thiamethoxam 25 WG (0.01%)	18.77f (10.36)	27.09e (20.74)	27.61f (21.48)
	S. Em. ±	0.83	0.69	1.73
	F test for treatment	Sig.	Sig.	Sig.
	C.V. (%)	5.08	3.20	6.57

Notes: 1) *Treatment means with common letter(s) are/is not significant at 5% level of significance by DNMRT
2) **Figures in the parentheses are re-transformed values and those outside are arc-sin transformed values

From the above results on toxicity of various insecticides evaluated in laboratory through topical application method it can be concluded that flonicamid (0.015%) and buprofezin (0.05%) considered to be relatively less toxic whereas, acetamiprid (0.006%), thiacloprid (0.013%) and spinosad (0.0135%) proved to be most toxic to grubs of *C. sexmaculata.* Imidacloprid (0.0089%), spiromesifen (0.0229%) and fipronil (0.01%) found moderately toxic to the grubs. Sheela and Shinde (2019) observed the least mortality of *C. sexmaculata* grubs at different interval of flonicamid after 12, 24, 48 and 72 hrs. Similarly, Jalali *et al.* (2009) also revealed that less mortality was found in flonicamid. According to the Sanghani *et al.* (2018) the buprofezin caused the lowest mortality at 24, 48 and 72 hrs. after treatment, of all stages tested, hence it can be considered as safer insecticide. Toxic effect of spinosad was noticed in present study. In contrast, Raguraman and Uthamasamy (2005) reported this insecticide to be safer for natural enemies. The difference in the results may be due to the difference in concentrations. Basappa (2007) and Awasthi *et al.* (2013) observed the toxic effect of acetamiprid which are similar to the results obtained. Similar results also found by Pirasanna *et al.* (2012).

Further, results revealed that acetamiprid found to be most toxic to ladybird beetles. But, in contrast Tank (2006), observed that acetamiprid and endosulfan proved safer insecticides. In contrast, Chakraborty (2012) reported that buprofezin, clothianidin and emamectin benzoate proved moderately toxic to adults of *C. sexmaculata* wherein they registered 67.61 to 71.56 % mortality. This might be due to the comparisions with more toxic insecticides and different concentrations

4.3.3. Adulticidal action:

Mortality data (Table 4.10 and figure 4.4) recorded at 24 hrs. after treatment indicated that minimum (0.02%) hazard was found in flonicamid followed by buprofezin (10.36%) and thiamethoxam (20.73%). These two treatments registered significantly lower mortality of *C. sexmaculata* over other insecticides evaluated. Imidacloprid, spiromesifen and fipronil proved moderately toxic to the adults of *C. sexmaculata,* as compared to others, by registering 32.90, 27.32 and 24.06 % mortality, respectively within 24 hrs. of exposure.

More or less similar trend of mortality in different treatments was noticed even after 48 hrs. of exposure period with slight increase in mortality level. The treatment of acetamiprid (65.23%) and thiacloprid (60.00%) showed increase in the level of mortality after 48 hrs. of treatment. A significant increase in mortality was recorded in imidacloprid (39.25%), spiromesifen (35.52%) and fipronil (32.20%) indicating its most toxic nature to the adults of *C. sexmaculata*. The treatments of flonicamid (0.02%), buprofezin (10.73%) and thiamethoxam (21.47%) registered significantly low mortality of the predator.

After 72 hrs. of exposure, flonicamid (10.00%) and buprofezin (11.56%) proved less toxic to the adults. The next among the less toxic, following flonicamid and buprofezin was thiamethoxam with 22.48 % mortality. The treatments of acetamiprid and thiacloprid proved to be the higher level of mortality (67.37% and 60.47%), but differed significantly.

From aforesaid results, it revealed that amongst the different insecticides evaluated, acetamiprid proved most toxic chemical to the adults of *C. sexmaculata*. This is in accordance with the report of Basappa (2007), Pirasanna *et al.* (2012) and Awasthi *et al.* (2013). In contrast to the present findings, Tank (2006) and Sheela and Shinde (2019) found acetamiprid as safer insecticide. Similarly, flonicamid and buprofezin found to have almost negligible effect to the predatory beetles. Similar results were found by Sheela and Shinde (2019), Sanghani *et al.* (2018), Pirasanna *et al.* (2012) and Jalali *et al.* (2009). However, in contrast to above, Chakraborty (2012) found that buprofezin was moderately toxic to *C. sexmaculata.*

Table 4.10. Effect of insecticidal treatments on adults of *C. sexmaculata* through topical application method

Sr. No.	Treatments	Corrected mortality (%) at indicated intervals (hrs.)		
		24	48	72
1	Acetamiprid 20 SP (0.006%)	48.94a (56.86)**	53.87a (65.23)	55.16a (67.37)
2	Buprofezin 25 SC (0.05%)	18.78f (10.36)	19.13f (10.73)	19.88g (11.56)
3	Fipronil 5 SC (0.01%)	29.38de (24.06)	34.58d (32.20)	36.10e (34.70)
4	Flonicamid 50 WG (0.015%)	0.91g (0.02)	0.91g (0.02)	18.44g (10.00)
5	Imidacloprid 17.8 SL (0.0089%)	35.00c (32.90)	38.80bc (39.25)	42.74c (46.06)
6	Spinosad 45 SC (0.0135%)	40.09b (41.47)	40.34d (41.90)	42.53c (45.69)
7	Spiromesifen 22.9 SC (0.0229%)	31.52cd (27.32)	36.59cd (35.52)	39.38d (40.26)
8	Thiacloprid 21.7 SL (0.013%)	46.06a (51.85)	50.77a (60.00)	51.04b (60.47)
9	Thiamethoxam 25 WG (0.01%)	27.09e (20.73)	27.61e (21.47)	28.31f (22.48)
	S. Em. ±	1.03	0.96	0.86
	F test for treatment	Sig.	Sig.	Sig.
	C.V. (%)	5.78	4.96	4.08

Notes: 1) *Treatment means with common letter(s) are/is not significant at 5% level of significance by DNMRT
2) **Figures in the parentheses are re-transformed values and those outside are arc-sin transformed values

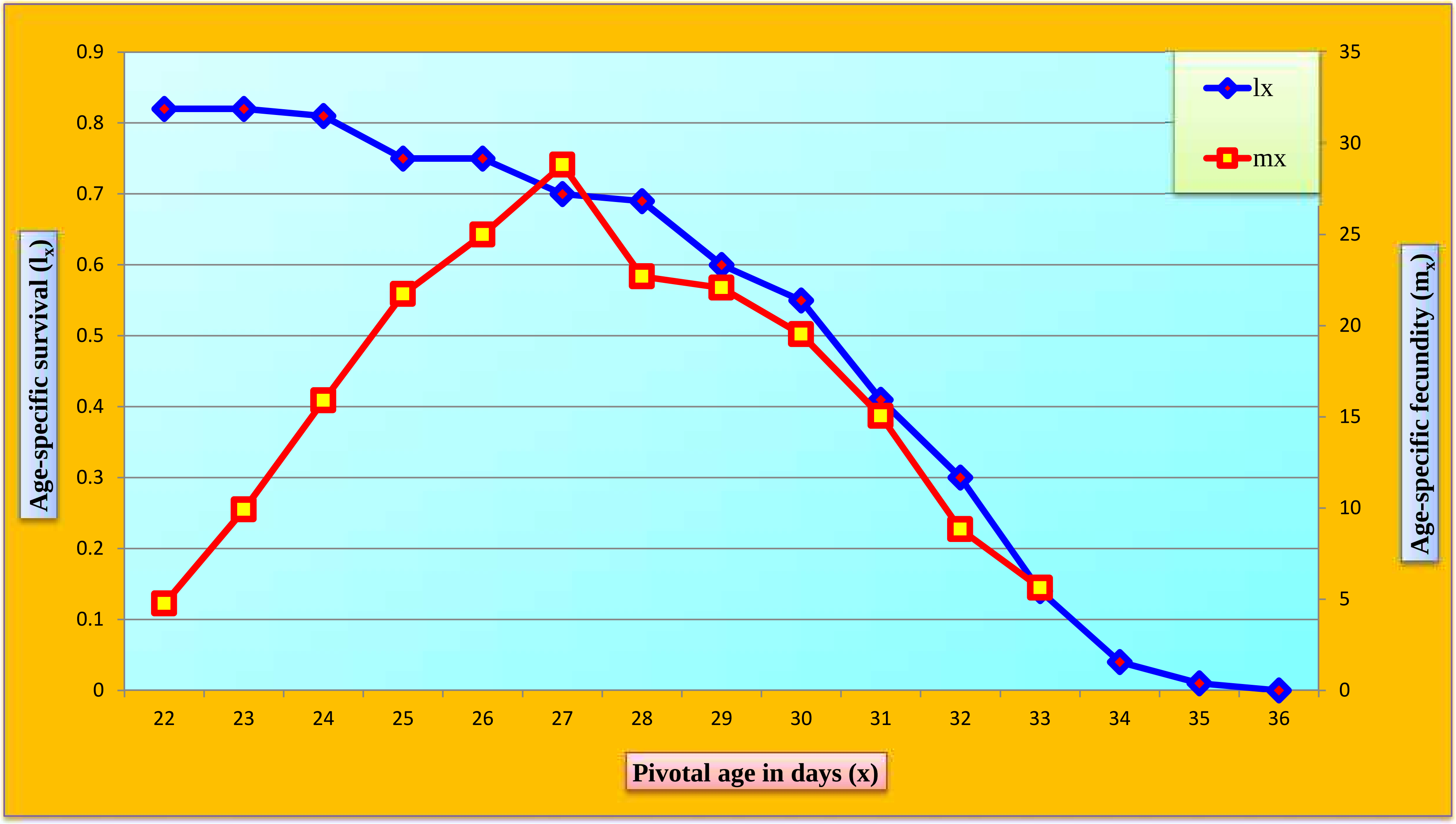


Figure 4.1: Age-specific survival and fecundity of *C. sexmaculata* reared on *A. gossypii*

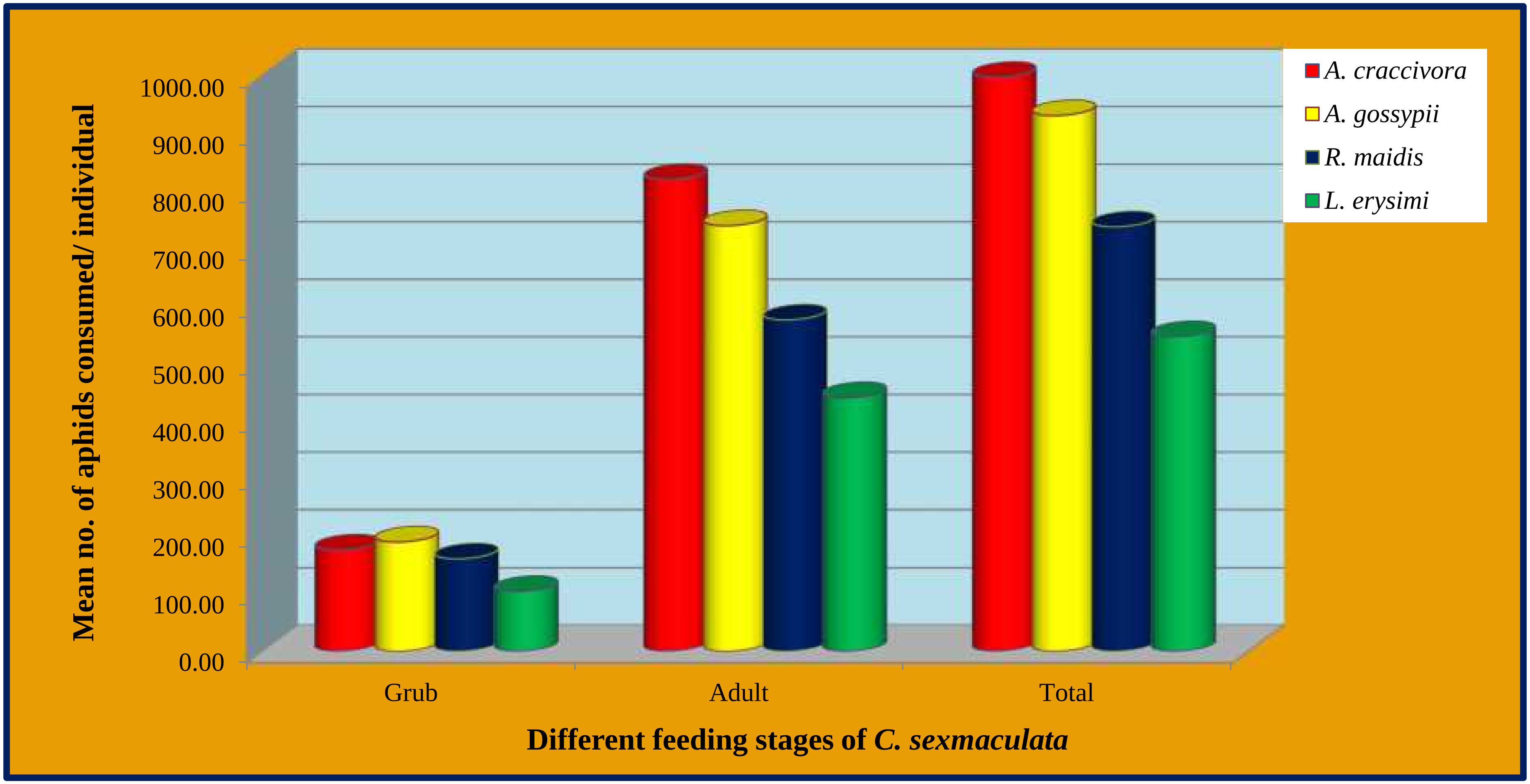


Figure 4.2: Feeding potential of *C. sexmaculata* on four different species of aphids

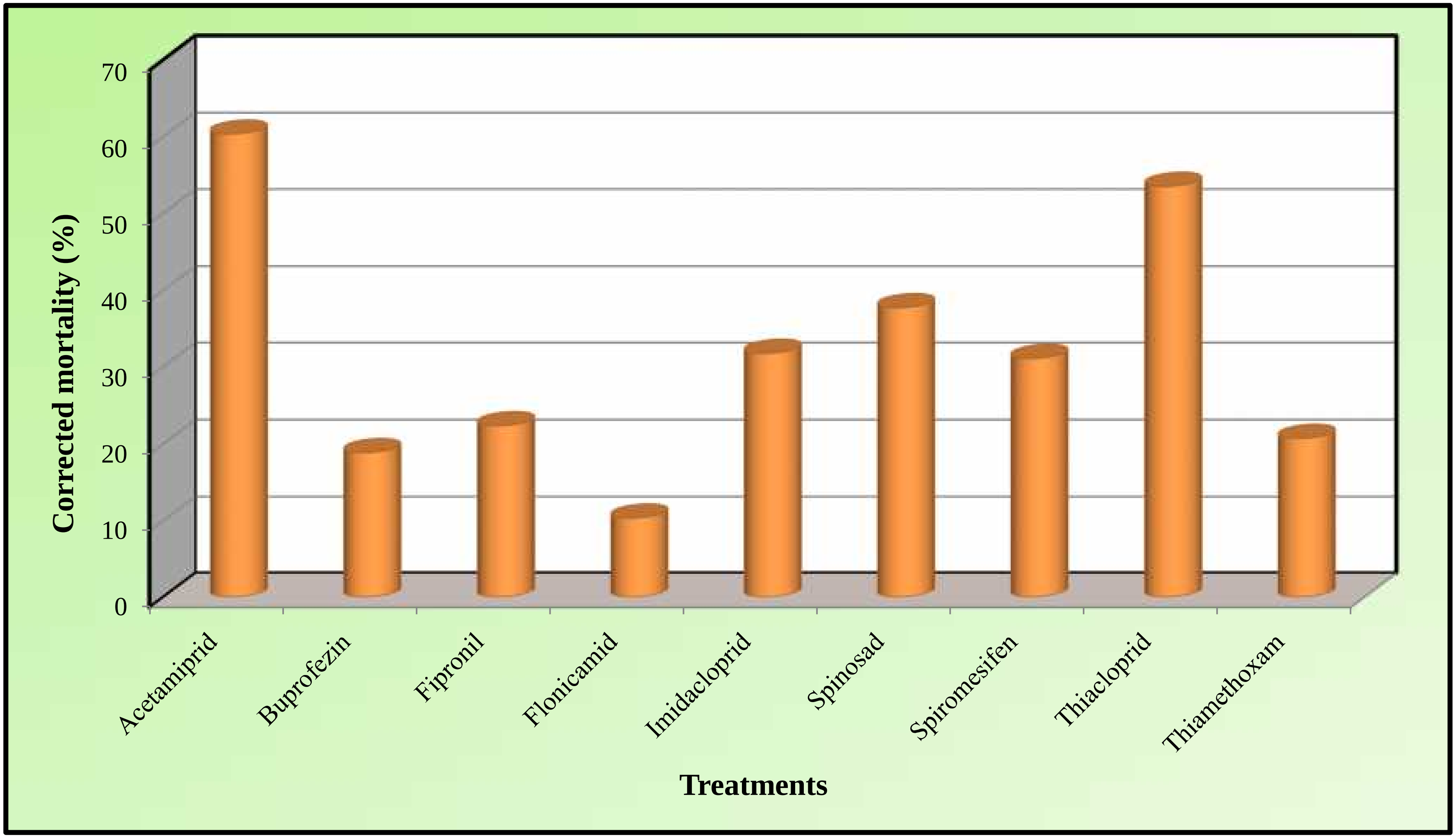


Fig. 4.3: Toxicity of various insecticidal treatments to eggs of *C. sexmaculata*

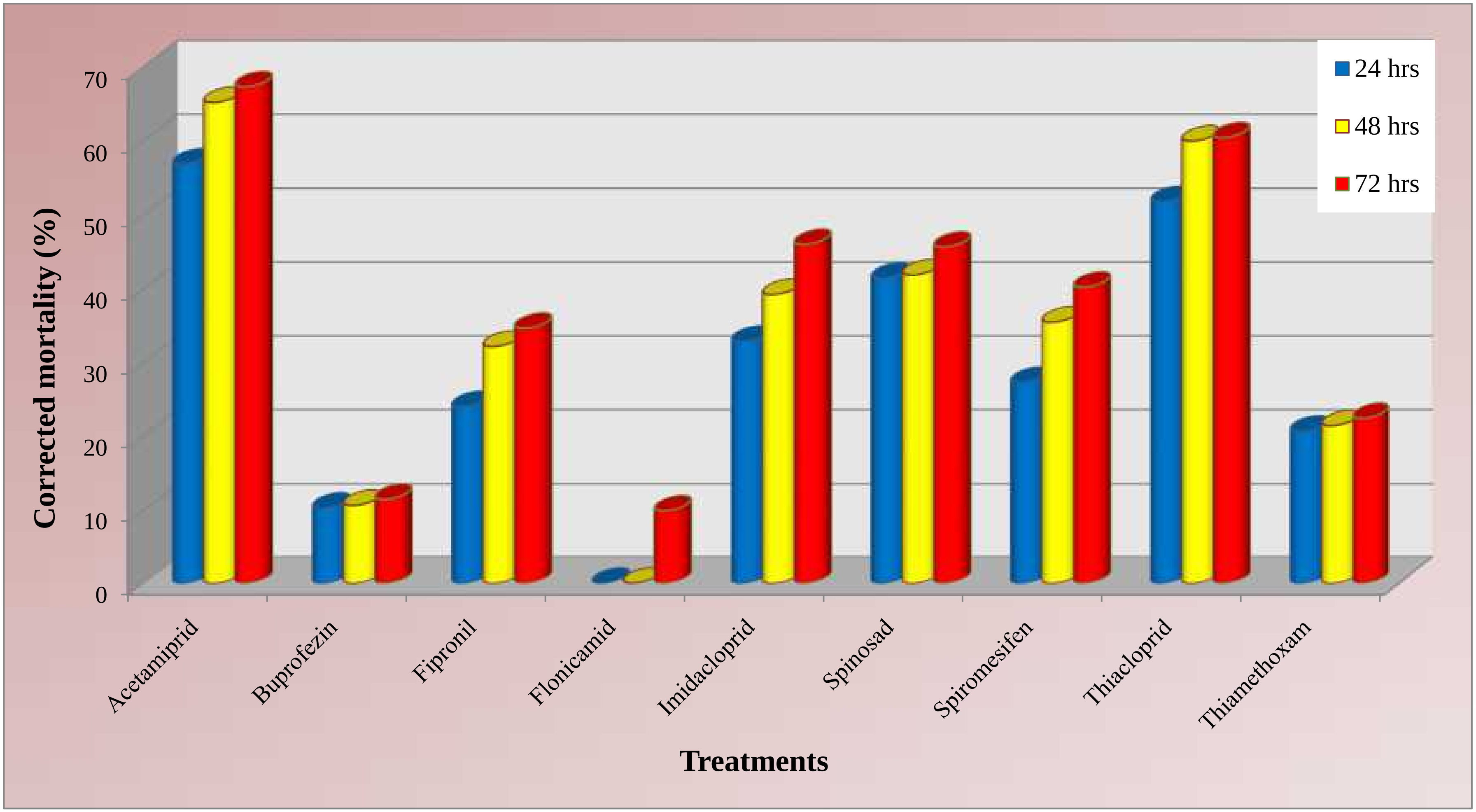


Figure 4.4: Effect of insecticidal treatments on adults of *C. sexmaculata*

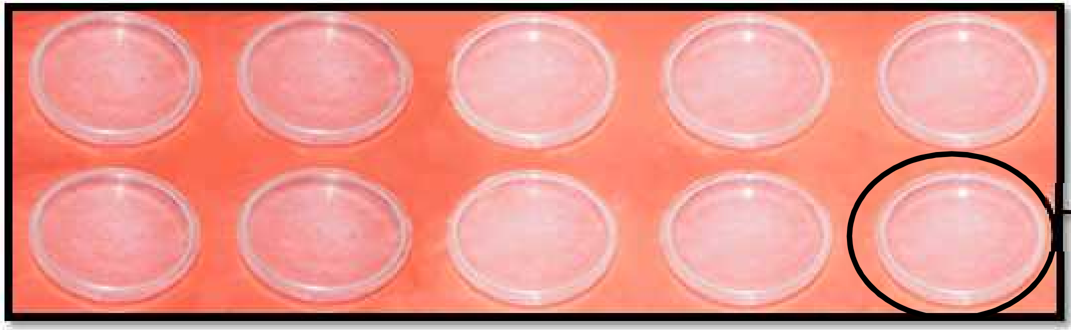
Plastic vial

B. O. D. incubator

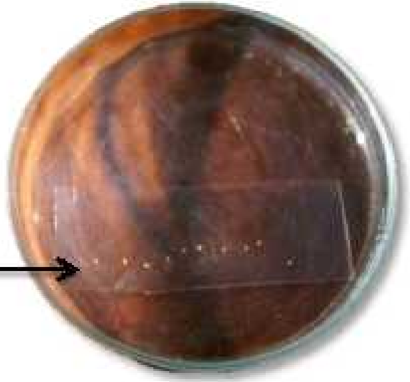
Aluminum cage

Plastic jar

PLATE I: Materials and instruments used for maintaining culture of *C. sexmaculata*



10 batches of eggs of *C. sexmaculata* in Petri dishes for life table



Enlarged view of 10 eggs on a petriplate

Rearing of *C. sexmaculata* in larval stage

Rearing of *C. sexmaculata* in adult stage

PLATE II: Rearing of different stages of *C. sexmaculata* for life table

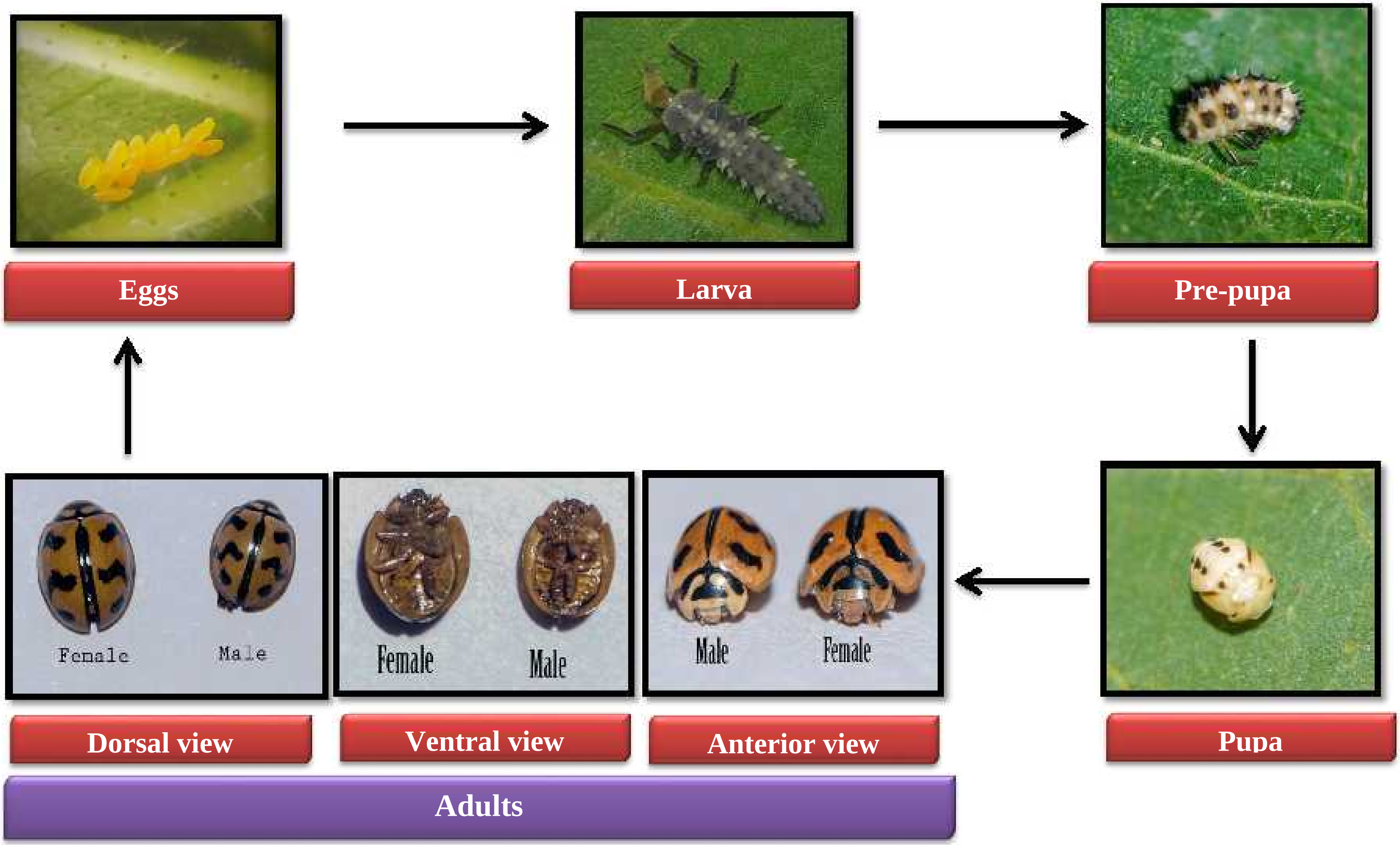


PLATE III: Different life stages of *C. sexmaculata*

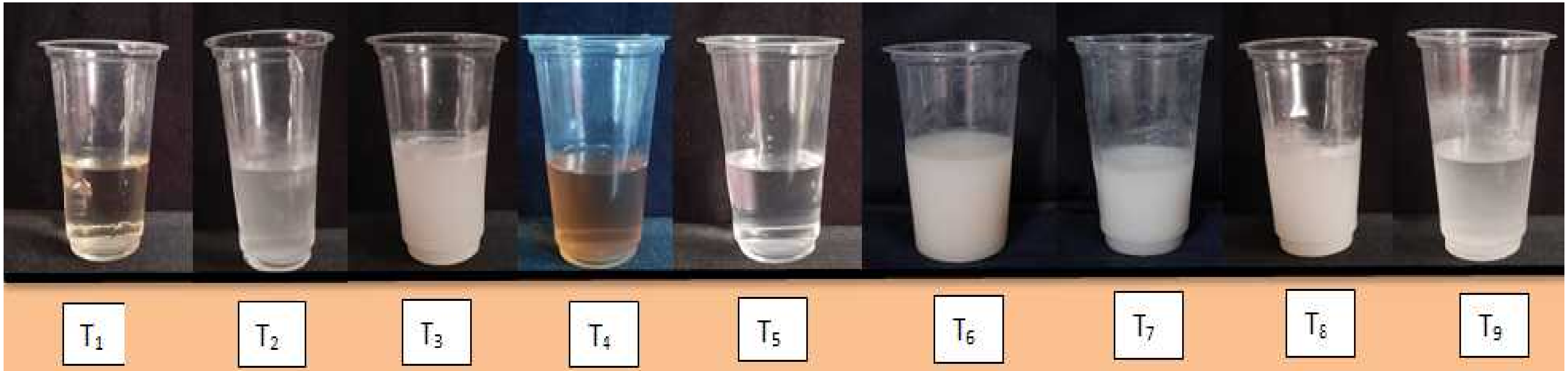
A. gossypii

R. maidis

A. craccivora

L. erysimi

PLATE IV: Experimental view of *C. sexmaculata* on four different species of aphids



T_1 = ACETAMIPRID 20 SP
T_2 = BUPROFEZIN 25 SC
T_3 = FIPRONIL 50 SC
T_4 = FLONICAMID 50 WG
T_5 = IMIDACLOPRID 17.8 SL

T_6 = SPINOSAD 45 SC
T_7 = SPIROMESIFEN 22.9 SC
T_8 = THIACLOPRID 21.7 SL
T_9 = THIAMETHOXAM 25 WG

PLATE V: Different insecticides used for evaluation of toxicity

5. SUMMARY AND CONCLUSION

Investigations on life table, feeding potential and relative toxicity to some insecticides to *Cheilomenes sexmaculata* (Fabricius) were carried out at Department of Agricultural Entomology, B. A. College of Agriculture, Anand Agricultural University, Anand (Gujarat) during 2019-20. The leading outcomes are summarized here in this chapter.

5.3.1. Life table of *C. sexmaculata* on *Aphis gossypii*

Investigation on life fecundity tables and age-specific distribution revealed that age specific fecundity (m_x) was recorded highest 28.82 on 27th day. The net reproductive rate (R_0) of this predator was recorded 129.47. The mean length of generation was observed to be 26.81 days. The innate capacity of increase in number (r_m) was 0.1871 per day. The finite rate of increase (λ) was worked out as 1.2057.

Studies on age-specific distribution of this predator on *A. gossypii* noticed that the eggs and larvae contributed the highest to the population of stable age, whereas the contribution of pre-pupal, pupal and adult stages was negligible. According to the observations of life expectancy e_x declined gradually with the advancement of development. The life expectancy of newly deposited eggs was 10.70 days.

5.2. Feeding potential of *C. sexmaculata* on different species of aphids

In order to assess the feeding potential of *C. sexmaculata* during its larval and adult stage, a laboratory study was carried out. An attempt was made to determine the comparative consumption ability of *C. sexmaculata* on four different species of aphids, *viz.*; cowpea aphid, cotton aphid, mustard aphid and maize aphid as prey.

Results obtained showed that highest number of aphids consumed by first instar was *A. craccivora* (20.13±0.61), second instar preferred *R. maidis* (35.27±0.49), while third and fourth instar larvae fed more on *A. gossypii*, with consumption of 57.87 ± 2.81 and 79.60 ± 1.99. It indicated that aphid consumption increased with the advancement of larvae from first to fourth instar, maximum being in case of fourth instar. The total consumption of grubs revealed that grubs of *C. sexmaculata* fed more on *A. gossypii* (191.20±4.17) closely followed by *A. craccivora* (177.10±5.48). The consumption capacity of *C. sexmaculata* adults indicated that *A. craccivora* (820.30±44.94) followed by *A. gossypii* (739.93±28.96). The least number of aphids eaten during grub and adult period was of *L. erysimi* (105.73±3.83 and 441.33±40.35). The total consumption by *C. sexmaculata* in its entire life time was more on *A. craccivora* (997.40±45.60).

The consumption ability of *C. sexmaculata* adults to different species of aphids can be arranged in descending order as: *A. craccivora* > *A. gossypii* > *R. maidis* > *L. erysimi.*

5.3. Relative toxicity of insecticides to *C. sexmaculata*

Among the nine insecticides *viz.*; acetamiprid, buprofezin, fipronil, flonicamid, imidacloprod, spinosad, sipromesifen, thiacloprid and thiamethoxam evaluated for their toxicity against *C. sexmaculata* in laboratory conditions, the flonicamid proved safer insecticides to the eggs of predatory coccinellids by registering least (10.36%) mortality. Acetamiprid and thiacloprid found relatively more toxic to eggs by exhibiting more than 50 % mortality.

Relative toxicity of insecticides was evaluated by two methods *viz.*; dry film method and topical application method, against grubs of *C. sexmaculata*. Based on overall mean values worked out for mortality due to the toxic effect of various insecticides, it revealed that among the insecticides assessed flonicamid caused significantly least mortality of *C. sexmaculata* followed by buprofezin suggesting its safer nature. Acetamiprid proved to be most toxic insecticide against grubs of *C. sexmaculata*. Acetamiprid was followed by thiacloprid and spinosad as they exhibited more than 50% mortality in both the methods. Imidacloprid and spiromesifen along with fipronil also found relatively less toxic to the grubs than acetamiprid, thiacloprid and spinosad, but were more toxic than thiamethoxam.

The same trend was observed in the results of bioefficacy of insecticides against adults showing acetamiprid, thiacloprid and spinosad had more that 50 % mortality. Imdacloprid, spiromesifen and fipronil found relatively less toxic to the adiults than above mentioned insecticides. While flonicamid, buprofezin and thiamethoxam proved safer insecticides to the adults of *C. sexmaculata.*

On the basis of toxic potential of insecticides to *C. sexmaculata*, the insecticides evaluated can be arranged in descending order as: acetamiprid > thiacloprid > spinosad > imidacloprid > spiromesifen > fipronil > thiamethoxam > buprofezin > flonicamid.

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APPENDIX

Appendix 1: Trial and error method for the calculation of intrinsic rate of natural increase (r_m) of *C. sexmaculata*

Pivotal Days (x)	**lxmx**	**0.18**		**0.19**	
		$e^{7-r_m x}$	$e^{7-r_m x}.l_x m_x$	$e^{7-r_m x}$	$e^{7-r_m x}.l_x m_x$
22	3.71	20.8987	77.6067	16.7719	62.2823
23	7.63	17.4563	133.2451	13.8700	105.8702
24	12.09	14.5810	176.2214	11.4701	138.6241
25	16.30	12.1793	198.4769	9.4855	154.5779
26	18.49	10.1732	188.1229	7.8443	145.0563
27	21.04	8.4976	178.7469	6.4870	136.4556
28	16.34	7.0979	115.9856	5.3646	87.6626
29	15.67	5.9288	92.9275	4.4364	69.5364
30	13.67	4.9522	67.7107	3.6688	50.1629
31	10.39	4.1365	42.9680	3.0340	31.5158
32	6.00	3.4552	20.7370	2.5091	15.0587
33	3.77	2.8861	10.8663	2.0749	7.8123
34	2.03	2.4107	4.8942	1.7159	3.4837
35	0.27	2.0136	0.5406	1.4190	0.3810
Total			**1309.0498**		**1008.4797**