परभक्षी ग्रीन लेस विंग, *मेलाडा बोनीनेन्सिस* (ओकामोटो) (न्यूरोप्टेरा : क्राइसौपिडी) के बडे पैमाने पर उत्पादन के लिये संभवित परपोषी की खोज

EXPLORATION OF POTENTIAL HOST FOR MASS PRODUCTION OF GREEN LACEWING, *Mallada boninensis* (Okamoto) (Neuroptera: Chrysopidae)

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EXPLORATION OF POTENTIAL HOST FOR MASS PRODUCTION OF GREEN LACEWING, *Mallada boninensis* (Okamoto) (Neuroptera: Chrysopidae)

By

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CERTIFICATE

This is to certify that the thesis entitled **"EXPLORATION OF POTENTIAL HOST FOR MASS-PRODUCTION OF GREEN LACEWING, *Mallada boninensis* (Okamoto) (Neuroptera: Chrysopidae)"** submitted to the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in **Entomology**, embodies the results of bona-fide research work carried out by **Elsiddig Ibrahim Yousif Roll No. 8893,** under my guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.

All the assistance and help received during the course of investigations are duly acknowledged by him.

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Elsiddig Ibrahim Yousif

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INTRODUCTION

Adoption of modern technology increases agricultural yield substantially. However, to save and protect this high yield from the ravage of pests, chemical pesticides are extensively utilized. The injudicious and indiscriminate application of these pesticides has resulted in several risks and injurious consequences such as health hazards, ecological imbalances, resistance in target pests, resurgence in minor pests and environmental pollutions. Therefore, utilization of biological control as a major component of any integrated pest management programme is crucially needed. The bio-control agents mainly include predators, parasitoids and pathogens (Gautam, 1994a).

The future development of biological control rests largely on increasing the diversity of bio-control agents that are mass-produced and improving the efficiency with which they are mass-reared. The commercialization of natural enemies and increasing their use in pest management requires; reducing the cost of mass-rearing and manipulating natural enemies, improving the success rate and predictability of biological control procedures and demonstrating the effectiveness and safety of biological control under commercial conditions (Tauber *et al.*, 2000).

Chrysopids have attracted considerable interest in recent years in view of their potential for biological control of pests in annual, perennial and protected crops, so, they can be used successfully in an IPM programme to improve the outcome and reduce the ecological hazards (Gautam and Tesfaye, 2002). Trash-carrying chrysopids appear well protected from intraguild predation and several species show excellent potential for commercialization (Tauber *et al.*, 2000; Nakahira and Arakawa, 2006).

The green lacewing, *Mallada* (=*Chrysopa* = *Anisochrysa*) *boninensis* (Okamoto) is one of the important, widely distributed chrysopid predators. Its larvae which carry the remains of their preys and other environmental trash on their backs (cryptic nature), are known to prey on a large number of soft bodied insect pest species *viz.*, aphids, aleyrodids, cicadillids, coccids, psyllids as well as eggs and young larvae of lepidopterans like *Helicoverpa armigera* (Hubner), *Phyllocnistis citrella* Stainton, *Diparopsis castanea* Hmps., *Spodoptera littoralis* (Boisduva) etc. in different agro-

ecosystems (Brettell, 1979; Lee and Shih, 1981; Nurindha and Indrayani, 1989; Joshi and Yadav, 1990; Mani and Krishnamoorthy, 1990; Selvakumaran *et al.*, 1996; Rao and Shivankar, 2002).They also attack and prey on mites (Lo *et al.*, 1990; Babu *et al.*, 2004). The adults are free-living feeding on honeydew, pollen and nectar of flowers (Gautam, 1994b; Williams, 1999).

Important characteristics of *M. boninensis* include its wide geographic distribution, wide host range in different habitats and ecosystems, its tolerance to some pesticides (Brettell, 1979; Brettell, 1984: Shivankar and Rao, 2004); also its voracious feeding larva and its amenability to mass multiplication in the laboratory on different hosts. Moreover, the behaviour of the larva in carrying trash on the dorsum of the abdomen provides camouflage and protects against intraguild predation (Anderson *et al.*, 2003; Babu *et al.*, 2004; Nakahira and Arakawa, 2006). The predator has a great potential for use against a large number of insect pests of both horticultural and field crops in combination with other integrated pest management methods. So, the species is an ideal biological control agent to be augmented for commercial utilization.

Literature concerning laboratory hosts for rearing *M. boninensis* larva was meager and reported in fragmented manner. It includes hosts like eggs of *Corcyra cephalonica* Stainton, eggs of *Tribolium castaneum* (Herbst), nymphs of *Aphis gossypii* (Glover), nymphs of psyllid, *Paurocephala psylloptera* Crawford, nymphs of some species of mealybugs, and larvae of *P. citrella* (Lee and Shih, 1981; Chen *et al.*, 1989; Kabissa *et al.*, 1989; Mani and Krishnamoorthy, 1989; Mani and Krishnamoorthy, 1990; Joshi and Yadav, 1990; Gautam, 1994c). However, no deliberate attempt has been made to screen for a suitable host/prey which can be easily produced in the laboratory with little effort, less hazardous, less cost, and can sustain the multiplication of the predator for many successive generations without deterioration of the progeny produced. Since, the quality of the bio-control agent is the ultimate goal of augmentation biological control; information on the effect of different prey species and stages on development and reproduction of the predator are prerequisites for successful utilization of these predators in biological control programmes (Osman and Selman, 1996).

Normally the widely used laboratory prey for multiplication of *M. boninensis* as well as other chrysopid predators is the frozen eggs of *C. cephalonica* (Lee and

Shih, 1981; Mani and Krishnamoorthy, 1989; Joshi and Yadav, 1990; Gautam, 1994b). Rearing of *C. cephalonica* is tedious and expensive due to the fact that, it needs large space, labour effort and controlled laboratory conditions. Besides, moths are collected manually; and the inhalation of the moths' scales causes respiratory problems to the workers (Jalali and Singh, 1989; Sreekumar, 1997). Recently, Tesfaye and Gautam (2002a) and Viji and Gautam (2005a) reported suitability of *Drosophila melanogaster* Meigen and *T. castaneum* larvae for rearing another green lacewing, *Chrysoperla carnea* (Stephens) in order to avoid hazardous and traditionally used host *C. cephalonica*. Therefore, there is an urgent need to explore an acceptable and suitable laboratory host (prey), which can be easily multiplied and managed in the laboratory with efficient cost and lesser threat to human health. Keeping this in view, the present investigation was carried out to select a suitable laboratory host for mass multiplication of *M. boninensis*.

Objectives

1. Exploration of suitable prey for the mass production of *Mallada boninensis* larva.
2. Effect of continuous rearing on various preys on the biological attributes of *M. boninensis*.
3. Construction of life tables for *M. boninensis* on the two most promising preys in the laboratory.
4. Cost of production of *M. boninensis* on the most suitable prey.

REVIEW OF LITERATURE

2.1 Morphological Description of *Mallada boninensis* (Okamoto)

Detailed description of adult male of *M. boninensis* was given by Adams (1959) under the synonymous name *Chrysopa boninensis* Okamoto as follows: head pale, black stripe on lateral margin of clypeus and spot on each gena; maxillary palpus black, labial palpus pale. Pronotum wider than long, anterior margin broadly curved. Mid-dorsal pale stripe faint. Wings fairly broad, tip blunt; venation pale, cubital crossviens in fore wing faintly dark. Setae dark, straight, short, numerous. Five to six inner, seven to eight outer, gradates in fore wing, apical inner gradates closer to Rs than are basal gradates. Ninth sternite narrowed behind to point; above shelf-like ridge with apical bulbous process each side. Paramere arms broad, space between arms sclerotized, deeply concave, bearing four heavy tapered setae on stalk-like bases. Gonapsis ligulate, with lateral arms and internal lobe of variable shape.

Joshi and Yadav (1990) described all life stages as follows: the egg is green, oval, stalked, 0.920±0.013mm long and 0.433±0.003mm wide, the stalk is 7.21±0.22mm long. The first instar is pink in colour and alligator shaped, with fine setae on body arising from dorso-lateral tubercles. The second and third instars are almost similar to each other, except in size and to some extent in colour. The third instar is larger and stouter than the second instar. They appear pink to brownish with prominent setae. The larvae are normally concealed by the remains of their preys. Cocoons are spherical, white in colour, 7.54±0.47mm in diameter and covered with the remains of the prey. The cocoons turn greenish a day or two before the emergence of adults. The adult is bright green, antennae longer than the length of the body. The sexes can easily be differentiated by their size and tip of the abdomen. The female is bigger in size and its abdomen is swollen. Male wing expanse is 2.63±0.19, while the female wing expanse is 3.13±0.13cm.

However, Kabissa *et al.* (1989) gave a description which could be used at field level to distinguish among four chrysopids [*Ceratochrysa antica* (Walker), *Chrysoperla* sp., *Brinckochrysa* sp., *and M. boninensis*]. They described adult of *M. boninensis* as

yellowish green in colour and larvae as trash carriers which pupate in spherical cocoons often covered with trash.

2.2 Taxonomy of *M. boninensis*

The green lacewings (Chrysopidae) are a cosmopolitan family of Neuroptera. The family includes over 1200 species and subspecies that are divided between 86 genera and subgenera. Identification of green lacewings is often very difficult because many species are superficially very similar. Furthermore, descriptions of species by earlier authors were often inadequate, being based on unreliable external features. Moreover, the problem of identification has been compounded by the uncertainty of the higher classification of the family (Brooks, 1983; Brooks and Barnard, 1990).

However, the higher classification of Chrysopidae was reviewed by Brooks and Barnard (1990). The authors recognized the three subfamilies Apochrysinae, Chrysopinae and Nothochrysinae, with the Chrysopinae subdivided into four tribes, Ankylopterygini, Belonopterygini, Chrysopini and Leucochrysini. They also re-described the 75 genera and the 11 subgenera included in the family.

Brooks and Barnard (1990) reported that *Mallada* is the largest genus of the Chrysopidae with at least 122 described species and, doubtless, many more remain to be described. This number includes 29 species from the Afrotropics, 8 from Madagascar, 19 species from the Indian subcontinent and the rest from other parts of the world.

Much controversy concerning taxonomy and nomenclature of this species prevails over a long period of time. Consequently, so many synonyms were given. Mansell (2000) gave the following account on taxonomy and synonyms.

Family: Chrysopidae (green lacewings)

Subfamily : Chrysopinae
Genus : *MALLADA*
= *ANISOCHRYSA*
Species : *M. boninensis* Okamoto
= *Mallada desjardinsi* (Navas)
= *Chrysopa desjardinsi Navas*
= *Chrysopa boninensis* Okamoto

= *Chrysopa serrandi* Navas
= *Chrysopa rutila* Esben-Petersen
= *Chrysopa obliqua* Navas
= *Chrysopa flavostigma* Esben-Petersen
= *Chrysopa inclinata* Navas
= *Mallada scolius* Navas
= *Chrysopa* (*Anisochrysa*) *boninensis* (Okamoto)
= *Anisochrysa boninensis* (Okamoto)
= *Mallada boninnsis*(Okamoto)
= *Mallada desjardinsi* (Navas)

Anonymous (2000) gave the following classification:

Family	:	Chrysopidae
Sub family	:	Chrysopinae
Tribe	:	Chrysopini
		Mallada desjardinsi (Navás)
		= *Chrysopa boninensis* Okamoto
		= *Chrysopa serrandi* Navás
		= *Chrysopa rutila* Esben-Petersen
		= *Chrysopa obliqua* Navás,
Type Depository	:	MNHN, Paris
Type Locality	:	Mauritius, 1 male.

In addition to the type of *M. desjardinsi* from Mauritius, this species is also known from the type of *C. boninensis* from the Bonin Islands, the type of *C. serrandi* from The Tamara Islands, the type of *C. rutila* from the Peros Banhos Atoll, and the type of *C. obliqua* from the Salomon Atoll in the Chagos islands. This species was recorded under the name *C. boninensis* from Japan, Taiwan, Ryukyu islands, Bonnin islands, Chagos islands, Cape Verde islands, South Africa, Zimbabwe, Mozambique, Kenya, Congo and Guinea (Anonymous, 2000).

2.3 Environmental Requirements

Concerning the environmental requirements of this species, very little work had been done on investigation of either field ecology or optimal laboratory conditions

suitable for survival and development. Chen *et al.* (1989) in China reported that the optimum temperature for predation by *M. boninensis* on citrus leaf miner was 35^0C.

Shivankar and Singh (1998) reported that temperature and relative humidity played an important role in the activity of all stages of the predator in the field. Temperature range of 28.8-32.2°C and relative humidity greater than 90% were the most conducive factors. The predator could not survive during summer when the temperature crosses 37°C. They also found that larvae of *M. boninensis* fed on blackfly nymphs and maintained at 35°C in BOD incubator could not survive for more than 4 days. Larvae fed on *C. cephalonica* eggs and kept at 34°C could not survive beyond 120 hours indicating the lethality of temperature.

However, Rao and Shivankar (2002) found that the population of the predator in farms of citrus in central India was negatively correlated with minimum temperature (-0.680) and vapour pressure (-0.876).

Nakahira *et al.* (2005) in Japan studied the thermal effects on development, survival, and adult body size of this species under the name *M. desjardinsi* along with another chrysopid, *Chrysopa nipponensis* (Okamoto) at seven constant temperatures (15.0, 17.5, 20.0, 22.5, 25.0, 27.5, and 30.0°C) with a photoperiod regime of 16: 8 [L: D] hr. They observed lower survival rate of *M. desjardinsi* in the egg stage at 30.0°C and in the cocoon stage at 15.0, 27.5 and 30.0°C. The body size of both green lacewings was affected by temperature throughout the range tested. Smaller body sizes of *M. (desjardinsi) boninensis* and *C. nipponensis* adults were observed at 15.0, 27.5 and 30.0°C.

2.4 Distribution, Host range and Ecosystem

M. boninensis is a generalist predator widely distributed in Africa, Asia and the islands of the Indian Ocean and the Pacific Ocean. Brooks and Barnard (1990) reported that this species occurs throughout the Afrotropics and Indo-Malaysia.

The species is wide spread and common in the subregion of Madagascar, Seyshelles, Mauritius, Mascarene Islands, Comoros, east Africa and wide spread in the African continent especially south of Sahara. It can be found in the continent of Africa from the Cape to Senegal and Cape Verde islands in east Africa to Somalia and Ethiopia and east ward to the Pacific (Ohm and Holzel, 2002). Holzel and Ohm (2002) reported

that the species extended into the Cape Verdes, occurs in almost all countries of South and Central Africa and extends over all islands of the Madagascan subregion as far as the Bonin Islands in Micronesia.

The larva attacks all life stages of a variety of soft bodied insect pests *viz.*, aphids, aleyrodids, cicadillids, coccids, psyllids as well as eggs and young larvae of many lepidopteran pests in different cropping patterns and agroecosystems (Brettell, 1979; Lee and Shih, 1981; Nurindha and Indrayani, 1989; Joshi and Yadav, 1990; Mani and Krishnamoorthy, 1990; Selvakumaran *et al.*, 1996; Rao and Shivankar, 2002). Besides, it also attacks and feeds on mites (Lo *et al.*, 1990; Babu *et al.*, 2004).

Rao and Satyanarayana (1984) reported *M. boninensis* in tobacco ecosystem preying on nymphs and adults of the aphid, *Myzus persicae* (Sulz.) in Andhra Pradesh. It was also reported among the predators of *Lipaphis erysimi* (Kalt) on Indian mustard in the field in Haryana, India (Kalra, 1988). The predator was considered among the important eight species of aphidophagous neuropterans recorded from northwest and western Himalayan part of Uttar Pradesh, India (Debnath *et al.* 1988).

Boussienguet (1986) reported this predator as one of the important natural enemies of the mealybug, *Phenacoccus manihoti* Matile-Ferrero on cassava in Gabon, Africa. Krishnamoorthy and Mani (1989) reported that *M. boninensis*, *Chrysopa lacciperda* Kimmins [*Plesiochrysa lacciperda*], *Anisochrysa basalis* (Walker) [*Mallada basalis*] and *C. carnea* were found preying on pseudococcids *viz., Planococcus citri* (Rossi) in citrus orchards and on *Ferrisia virgata* (Cockerell) and *P. citri* in guava orchards. They also recorded *M. boninensis* and *Apertochrysa* sp. preying on *Maconellicoccus hirsutus* [Cockerell]) in vineyards. Miyanoshita and Kawai (1992) reported predation by larvae of *M. boninenis* on *Ceroplastes japonicus* Green (Homoptera: Coccidae) on *Euonymus japonicus* Thunb in Japan causing a major mortality factor during summer.

M. boninensis, recorded from Gujarat preying on the whitefly, *Bemisia tabaci* Gennadius in cotton fields (Joshi and Yadav, 1990). It was also reported on the whitefly, *Lipaleyrodes euphorbiae* David & Subramaniam on star gooseberry, *Phyllanthus acidus* in Bangalore, India (Mani and Krishnamoorthy, 1995), and on the whitefly, *Kanakarajiella cardamomi* (David and Subramaniam) a pest of cardamom

(Selvakumaran *et al.*, 1996). Charati *et al.* (2003) reported that *M. boninensis* is one of the most important natural enemies of the spiralling whitefly, *Aleurodicus disperses* Russell on different crops like guava, banana, mango, coconut, groundnut and pigeon pea.

M. boninensis was reported preying on nymphs of *Idioscopus clypealis* (Lethierry), *I. nitidulus* (Walker) and *Amritodus atkinsoni* (Leth.) in mango ecosystem in Uttar Pradesh (Fasih and Srivastava, 1990). The predator also attacks cicadellid pests, including *Amrasca biguttula biguttula* Ishida, *Empoasca sp.*, *Peregrius maidis* (Ashmead), *Kolla ceylonica* (Melichar) and *Exitianus indicus* (Distant) in a variety of crops (including cereals, grain legumes, oilseed crops, fibre crops, sugar crops, vegetables, fruits and forage crops) (Singh *et al.*, 1993).

Brettell (1979, 1984) reported this predator from unsprayed cotton fields in central Zimbabwe preying on cotton pests like aphids and bollworms. Kabissa *et al.* (1989) reported that the larvae of *M. boninensis* in cotton fields in Tanzania are commonly found in association with cotton aphids and they readily preyed on eggs and 1^{st}-3^{rd} instar larvae of *H. armigera* when these were presented to them in the laboratory.

However, Kabissa *et al* (1996) reported this species under the name *M. desjardinsi* in cotton ecosystem preying on *Aphis gossypii* (Glover) and *H. armigera.* They mentioned that this predator was noted preying on aphids on sorghum sown before cotton; so such sorghum depending on its state of growth and proximity to cotton may serve to encourage early colonization of the cotton crop by this predator and other chrysopids. *M. boninensis* was also recorded as one of the most important natural enemies of the noctuid *H. armigera* on cotton in Indonesia (Nurindah and Indrayani, 1989).

Rao and Shivankar (2002) reported *M. boninensis* in citrus ecosystem on citrus leaf miner, *P. citrella.* The species is considered an important predator of citrus insect pest *viz.*, citrus blackfly, psylla, leaf miner, aphids and mealybugs (Satpute *et al.*, 1989; Shivankar and Rao, 2002). In China, the lacewing *M.* (*Chrysopa*) *boninensis* is considered an important natural enemy of the psyllid *Diaphorina citri* Kuwayama (Hoy *et al.*, 2003).

The host plant-mediated orientational and ovipositional behaviour of *M. boninensis* and two other chrysopids to cotton, sunflower and pigeon pea, *Cajanus cajana* (L.) was studied in the laboratory. Males of *M. boninensis* did not show a specific preference for any of the three host plants, while females preferred cotton (Ballal and Singh, 1999).

M. boninensis is one of the predominant chrysopid predators in Guangzhou, China. It completes 10-11 overlapping generations a year. All stages in the life cycle could be found in the field throughout the year (Wei *et al.*, 1986; Wei *et al.*, 1987).

M. boninensis is also considered among the important predators of tetranychid spider mites in Taiwan (Lo *et al.*, 1990). Babu *et al.* (2004) reported *M. boninensis* feeding on eggs, nymphs and adults of the red spider mite, *Oligonychus coffeae* (Nietner), infesting tea in Kerala, India. They observed that newly emerged larvae preferred eggs and quiescent stages of the red spider mite, while later instars showed preference for neonates and adult mites.

2.5 Behaviour

The larvae of *M. boninensis* and some other chrysopids are characterized by the behaviour of carrying trash on their backs (Joshi and Yadav, 1990; Lopez *et al.*, 1999; Tauber *et al.*, 2000; Nakahira and Arakawa, 2006). The trash composed of discarded prey items and other environmental debris which act as a camouflage to protect against natural enemies and cannibalism by individuals of the same species.

Lopez *et al.* (1999) reported that trash-carrying chrysopids within the genus *Ceraeochrysa* appear well-protected from intraguild predation, and several spp. show excellent potential for commercialization in the United States and Latin America.

Anderson *et al.* (2003) found that larvae of the native Australian chrysopid *Mallada signata* (Schneider) used discarded prey items and environmental debris carried on the dorsal abdominal segments, as camouflage. Larvae that carry trash were confirmed experimentally to experience lower rates of cannibalism, an effect attributed to the camouflage conferred by the package. Larvae preferred physically hard material over normal dietary items when constructing their trash-package. The authors suggested that inclusion of these materials may provide both physical and chemical camouflage from predator and prey alike.

Nakahira and Arakawa (2006) elucidated the defensive functions of the trash-package of the green lacewing *M. desjardinsi* larva against the ladybird *Harmonia axyridis* (Pallas). The contact frequency, attack rate, and capture rate of ladybirds were compared between the 'with trash' or 'naked' treatments of the green lacewing. The contact frequency until the ladybird captured the green lacewing was significantly more in the 'with trash' treatment (median: four times) than in the 'naked' treatment (median: one time), which indicates that the trash-package of the green lacewing offers protection from predation by ladybirds. The attack rate of the ladybirds on the 'with trash' green lacewing larvae (55%) was significantly lower than that on the 'naked' ones (90%). After the ladybirds first attacked, their capture rate of the 'with trash' green lacewing larvae (18%) was significantly lower than that of the 'naked' ones (83%). Thus, the trash-package of the green lacewing affords prevention against recognition (primary defense) and subjugation (secondary defense) from the ladybird.

Mochizuki *et al.* (2006) studied the potential competitive risk of the introduced *C. carnea* on the indigenous trash-carrying *M. desjardinsi*, they studied the occurrence of cannibalism and intraguild predation (IGP) at different prey densities. In *C. carnea*, 100% cannibalism was observed in the absence of aphids. In *M. desjardinsi*, cannibalism was also observed, but absence of cannibalism occurred at 35-70%. In pairs of *M. desjardinsi* larvae whose trash package had been artificially removed, all third-instar larvae ate second-instar larvae. IGP occurred in all pairs of different instars. When third-instar larvae of both species were paired, *C. carnea* larvae ate significantly greater numbers of *M. desjardinsi* larvae than vice versa.

2.6 Biology of *M. boninensis*

The biology of *M. boninensis* was studied on some hosts (Brettell, 1979; Lee and Shih, 1981; Mani and Krishnamoorthy, 1989; Chen *et al.*, 1989; Joshi and Yadav, 1990; Mani and Krishnamoorthy, 1990; Kabissa *et al*, 1995; Shivankar and Singh, 1998). On different hosts, they observed varying developmental periods of the life stages of the predator as well as variations in adult fecundity and longevity, which are important attributes for a bio-control agent to be augmented.

Brettell (1979) studied the biology of *M. boninensis* in Rhodesia (Zimbabwe). He reported that the duration of the egg, larval, and pupal stages averaged 3.7, 12.0, and

10.0 days, respectively at 25^{0}C; the adult life span averaged 31.4 days in females and 21.0 days in males.

Lee and Shih (1981) reported that the type of prey influenced the life cycle of *M. boninensis*. They successfully reared the predator in the laboratory on either nymphs of the psyllid, *Paurocephala psylloptera* Crawford or eggs of the pyralid moth, *C. cephalonica* and found that the life cycle was shorter on the latter. On *P. psylloptera*, the mean lifetime of the females was 47.9 days and that of the males was 43.0 days; the reproductive rate 12.74 eggs/female/day and females laid an average of 512.3 eggs each. The pre-oviposition period lasted 4 -11 days and the oviposition period 11- 80 days.

Kabissa *et al.* (1989) reared the larvae of *M. boninensis* as well as two other chrysopids on 1st instar nymphs of *Aphis fabae* Scopoli in Tanzania. Kabissa *et al*, (1995) studied the developmental biology of *M. boninensis* on *H. armigera* and *A. gossypii* in the laboratory at 28-32°C. The total larval period on *H. armigera* eggs was 14.4 days while 14.9 days on *A. gossypii*. On an average 52.9% of 3rd instar larvae died before pupation when reared on *H. armigera*, as against 82.6% on *A. gossypii*. They concluded that *H. armigera* eggs and *A. gossypii* nymphs were both adequate but not optimal diets for larval development.

Mani and Krishnamoorthy (1989) found that the development of *M. boninensis* was completed in 21.85 days on eggs of *C. cephalonica* and 25.5 days on the grapevine mealybug, *M. hirsutus*. Larval period on *C. cephalonica* was 9.25 days and 11.30 days on *M. hirsutus*, while the cocoon period was 8.35 and 10.10 days on the rice moth and the mealybug, respectively. The biology of the predator on other mealybugs *viz.*, *F. virgata*, *P. citri* and *Planococcus lalicinus* (Ckll.) was studied by Mani and Krishnamoorthy (1990) at 25±2^{0}C and 65-75% RH. They reported egg incubation period of 4-5 days, larval period of 10.2-11 days and pupal period of 8-10 days. The type of prey (kind of mealybug) did not influence the length of the development period. They reported adult emergence of 82-90% from the pupae produced from rearing larvae on different mealybug spp. The life cycle completed in 22-26 days.

Chen *et al.* (1989) studied the biology of *M. boninensis* on larvae of citrus leaf miner, *P. citrella* in China. They found that male lived for 61.8 days and female for

101.7 days, laying an average of 400 eggs. On an average each individual larva consumed 149.1 larvae of *P. citrella*.

Joshi and Yadav (1990) studied the biology of *M. boninensis* on frozen eggs of *C. cephalonica* and nymphs of whitefly, *Bemisia tabaci* (Gennadius) in Gujarat under laboratory conditions of 25.26±2.2^{0}C and 59.9% RH. They reported that the predator laid green, oval, stalked eggs in groups of 11-20 each group, an average egg incubation period of 4.69 (4.5-5.0) days, larval period of 12.5 days with three instars the duration of which were 4.11, 4.11 and 4.63 days. The pre-pupal and pupal periods averaged 5-7 hour and 13.79 days, respectively. The sex-ratio was 1:1.5 (male: female) and the per cent emergence was 81.4. Average pre-oviposition, oviposition and post-oviposition periods were 9.9 (4-11), 36.9 (11-88) and 18.0 days, respectively. Female laid on average 431 eggs during its lifetime. The mean longevity of female and male was 64.8 and 27.36 days, respectively. They also reported that the larval period reared on *B. tabaci* nymphs was 11.66 days as compared to 12.5 days on eggs of *C. cephalonica*.

Shivankar and Singh (1998) at Nagpur, reported that the life cycle of *M. boninensis* was completed in 30-35 days (egg to adult) with adult female longevity being 35±5 and that of male 7-15 days. The pre-oviposition period was 6-8 days, the egg incubation period was 3-4 days, and female fecundity was 200-300 eggs. The larval period was 13-14 days and the pupal period was 7-9 days. Egg hatchability in the laboratory culture was 85-100%, larval to pupal conversion 90-100% and pupal to adult 90-100% at optimum temperature and relative humidity. The sex-ratio was nearly 50: 50 (1: 1).

Rao *et al.* (2003) studied the feeding potential and development of *M. boninensis* at 26±2°C and 65±5%R.H., on the citrus leaf-miner, *P. citrella* kept on different citrus spp. They reported an average larval period of 11.9-15.1 days, pupal period of 9.3-10.9 days, pupal survival of 43.4-64.3%, adult longevity of 22.4-27.9 days, and fecundity of 95.4-115.7 eggs.

Nehare *et al.* (2004) studied the biology and predatory potential of *M. boninensis* on different sucking pests *viz.*, eggs and nymphs of citrus blackfly, *Aleurocanthus woglumi* Ashby; nymphs of citrus psylla, *Diaphorina citri* Kuwayaman; nymphs of different aphids (*A. gossypii, A. craccivora, L. erysimi* and *Uroleucon compositae*

Theobald) and eggs of *C. cephalonica* in the laboratory under controlled temperature and humidity conditions of 26±2°C and 65±5%RH, respectively. The longest larval duration was observed as 16.66 days when reared on nymphs of *U. compositae*, while the shortest pupal duration was recorded as 8.26 days when larvae were reared on eggs of *A. woglumi*. Maximum adult longevity of male (37.06 days) was observed when their larvae were grown on nymphs of *A. woglumi* and maximum longevity of female (53.22 days) and oviposition period of 46.6 days were recorded with eggs of C. *cephalonica* as a larval food. The shortest pre-oviposition period of 4.4 days and longest incubation period of 4.53 days was recorded with the diet of nymphs of *A. woglumi*. They concluded that on the basis of influence on the various biological parameters of the predator, it could be inferred that the laboratory host *i.e.* eggs of *C. cephalonica* was found to be the most suitable host for rearing and nymphs of *A. woglumi*, and *A. gossypii* can be used as substitute.

2.7 Life Tables

Life table is one of the most useful tools in the study of population dynamics of insects. It is a concise summary of certain vital statistics of the species population which provides a format for recording and accounting all population changes in the life cycle of the species (Hemchandra and Singh, 2005). The cohort life table gives the most comprehensive description of the survivorship, development and reproduction of a population, and as such, is fundamental to both theoretical and applied population ecology (Chi and Yang, 2003; Das and Chaudhuri, 2005). The study of life tables of different species of predators will provide the much needed data for their multiplication a pre-requisite in pest management (Bakthavatsalam *et al.*, 1994). According to Andrewartha and Birch (1954) and Jervis *et al.* (2005) important statistics to be considered in life table studies include:

i. Intrinsic rate of natural increase (r_m); also called innate capacity for increase which was defined by Andrewartha and Birch (1954) as the maximal rate of increase attained at any particular combination of temperature, moisture, quality of food, and so on, when the quantity of food, space, and other animals of the same kind are kept at an optimum and other organisms of different kinds are excluded from the experiment. The r_m depends upon fecundity, longevity, and speed of development. The r_m is a useful indicator of the potential rate of growth

of an insect population under a given set of environmental conditions (Shazali, 1986). Jervis *et al.* (2005) stated that, prey species can influence the intrinsic rate of natural increase of predators.

ii. Capacity for increase $r_c = \log_e R_0/T_c$. It is a good approximation for r_m when R_0 and thus population size remains constant, or when there is little variation in generation length or for some combination of these two factors (Jervis *et al.*, 2005).

iii. Finite rate of increase [lambda (λ) $=e^{rm}$], it combines births of new individuals and the survival of existing individuals. So, it is the number of times a population multiplies in a specified time interval and is the antilog of r_m (Shazali, 1986; Jervis *et al.*, 2005). If $\lambda>1$ the population increases, if $\lambda<1$ the population decreases. It is called the geometric growth rate.

iv. Gross reproductive rate (GRR = Σm_x), it is the mean total number of eggs produced by females over their lifetimes, measured in females per female per generation.

v. Net reproductive rate ($R_0 = \Sigma l_x m_x$) which is the number of female offspring produced per female per generation (Gilreath and Smith, 1987).

vi. Aproximate Generation time $T_c = \Sigma x l_x m_x / \Sigma l_x m_x$.

vii. Generation time (T) is the average length of time from the birth of an individual to the birth of its offspring measured in days.

viii. Doubling time (DT $=\log_e 2/r_m$) it is the time, measured in days, required for a given population to double its numbers.

Lee and Shih (1981) constructed the life table of *M. boninensis* in the laboratory on nymphs of *P. psylloptera,* in Taiwan. They estimated the intrinsic rate of natural increase (r_m), net reproductive rate (R_0), and generation time (T) as 0.0964, 181.5 and 54.2, respectively. These statistics were estimated by Bakthavatsalam *et al.* (1994) for this predator reared on eggs of *C. cephalonica* as 0.3329, 191.71 and 17.999, respectively.

2.8 Tolerance to Pesticides

The use of bio-control agents in the field as part of an integrated pest management programme benefits much by exploiting those bio-control agents which tolerate the use of some pesticides, whenever critical situation of pest density is reached. The tolerance level of *M. boninensis* to some pesticides is reviewed here under.

Brettell (1979) tested four insecticides used in cotton fields in Zembabwe against 3rd instar larvae of *M. boninensis*. The LC_{50s} were found to be 4.39% for carbryl, 1.349% for endosulfan, 0.26% for dimethoate and 0.07944% for DDT. They concluded that DDT and dimethoate were highly toxic to the larvae of *M. boninensis*.

Brettell (1984) studied the toxicity of some acaricides and insecticides against 3rd instar larvae of *M. boninensis*. They found that among the acaricides, triazophos was very toxic (LC_{50}, 0.01-0.02%), binapacryl was less toxic (LC_{50}, 1.58 to>10%), and amitraz and tetradifon were so inactive that their LC_{50} could not be calculated. The LC_{50} of pyrethroid insecticides ranged from 0.02-0.86% where as the carbamate thiodicarb had LC_{50} of more than 19%.

Mani and Krishnamoorthy (1991) found that *M. boninensis* and some other predators are highly susceptible to the contact toxicity of the synthetic pyrethroid insecticides, fenvalerate (0.05%), cypermethrin (0.005%) and deltamethrin (0.0014%). They concluded that the use of synthetic pyrethroids in orchards when predators are actively feeding is not advisable.

Shivankar and Rao (2002) evaluated ethanol extracts of six locally available plant products (*Alpinia galanga* (L.), *Acorus calamus* L., *Nerium odorum* Sol., *Vitex negundo* L., *Cymbopogon nordus* (L.) and *Azadirachta indica* A. Juss. for their selectivity against the 2nd instar larvae of *M. boninensis*. The results revealed that *A. galanga* and *A. calamus* were safer to *M. boninensis* larvae as compared to other botanicals tested.

In a separate study, the extracts of the botanicals *A. galanga* and *A. calamus* were found safer to larvae and adults of *M. boninensis* than *N. indicum*, *V. negundo* and *A. indica* (Shivankar and Rao, 2004). Patel and Vyas (2000) found that *Bacillus thuringiensis* sub sp. kurstaki formulations (Btk; Cutlass, Delfin and Bactec) were less toxic to *M. boninensis* and other predators than chemical pesticides and neem based formulations in cotton fields.

2.9 Feeding Potential

The larvae of *M. boninensis* are very voracious and have a high predatory (feeding) potential. The feeding potential has been worked out on many host species *viz.*, *M. hirsutus* (Mani and Krishnamoorthy, 1989); *F. virgata*, *P. citri* and *P. lilacinus* (Mani and Krishnamoorthy, 1990); the psyllid *P. psylloptera* (Lee and Shih, 1981); larvae of *P. citrella* (Chen *et al.*, 1989; Rao *et al.*, 2003); eggs of *H. armigera* and nymphs of *A. gossypii* (Kabissa *et al*, 1995); eggs of *C. cephalonica* and nymphs of *B. tabaci* (Joshi and Yadav, 1990; Nehare, *et al.*, 2004). According to them a single larva during its developmental period consumed a total of 628.75-734.66 eggs, of *C. cephalonica*, 135.5 eggs of *H. armigera*, 189.5 nymphs of *A. gossypii*, 562 nymphs of *P. citri,* 490.25 nymphs of *P. lilacinus,* 344.7 nymphs of *F. virgata*, 453 nymphs of *B. tabaci*, 437.7 nymphs of *P. psylloptera* or 104.8-149.3 larvae of *P. citrella.* Rao *et al.* (2003) reported that the feeding potential of *M. boninensis* larvae on citrus leaf miner, *P. citrella* was influenced by the citrus species on which the larvae of the leaf-miner were reared.

The number of prey consumed by larvae of *M. boninensis* increased with instar (Lee and Shih, 1981; Mani and Krishnamoorthy, 1990; Kabissa *et al*, 1995). According to Mani and Krishnamoorthy (1990) first instar preyed on 40.20 to 62.66 nymphs of mealybug depending on the mealybug species. The number of nymphs preyed by the second instar larva varied from 66.83 to 123.80. Third instar larva was very voracious consuming more number of nymphs than the first and second instars together (199.00 to 398.00).

Lee and Shih (1981) reported that larva of *M. boninensis* consumed on an average 5.6, 13.96, and 62.87 nymphs of *P. psylloptera* prey per day in the 1st, 2nd and 3rd instars, respectively. However, Shivankar and Singh (1998) reported that the larva of *M. boninensis* requires 75.12 *C. cephalonica* eggs or 15-16 citrus blackfly, *A. woglumi* nymphs per day. They also quantified that 0.40g of *C. cephalonica* eggs were required for 10 larvae to attain full growth.

Ramkumar *et al.* (2005) recorded mean predatory potential on eggs of *C. cephalonica*; eggs, second, third and fourth instar nymphs of *A. woglumi* as 724.7, 1872.79, 1313.99, 960.02 and 1013.98, respectively.

2.10 Mass-production

Chrysopids are normally mass-produced on eggs of stored grain moths like *Anagasta kuehniella* (Zeller), *Sitotroga cerealella* (Oliver) and *C. cephalonica* world wide (Lee and Shih, 1981; Gautam, 1994b; Lopez *et al.*, 1999).

M. boninensis in India is mass-produced on eggs of *C. cephalonica*. Gautam (1994b) standardized a method for mass-rearing of *C. carnea*, *Mallada* sp. and *M. boninensis* on frozen eggs of *C. cephalonica*. Jalali *et al.* (2003) reported that total quantity of *C. cephalonica* eggs required for rearing 100 chrysopid larvae is 5.0cc. Bakthavatsalam *et al.* (1994) pointed out the non-preference of *C. cephalonica* eggs for feeding larvae of *M. boninensis* as well as three other chrysopids.

Nehare *et al.* (2004) reared larvae of *M. boninensis* on different sucking pests *viz.*, eggs and nymphs of citrus blackfly, *A. woglumi*; nymphs of citrus psylla, *D. citri*; nymphs of different aphids (*A. gossypii*, *A. craccivora*, *L. erysimi* and *U. compositae*) and eggs of rice moth, *C. cephalonica*. They concluded that eggs of *C. cephalomica* was found to be the most suitable host for rearing larvae of *M. boninensis* while nymphs of *A. woglumi*, and *A. gossypii* can be used as substitute.

Viji and Gautam (2005a) reared another chrysopid, *C. carnea* on different laboratory hosts. They identified *T. castaneum* and *D. melanogaster* larvae as best alternative hosts to C. *cephalonica* eggs. They observed significantly high incubation period, prepupal period, pupal period, fecundity and longevity on *T. castaneum* larvae as against *C. cephalonica* eggs.

Gautam and Paul (1988) pointed out the influence of food supplements on the reproductive behaviour of a chrysopid predator, *Chrysopa scelestes* Banks. They found high degree of dependence on the type of food provided to the adults. The preoviposition period was reduced to 3.60 days when adults fed on the flowers of ganja, *Cannabis sativa* L. as against 10.4 days obtained on 50% honey (control). They also found significant effect of food supplements on longevity of males and females, the fecundity of females increased many fold in case of adults fed on composite feed, pollens of castor or maize. The egg hatchability was not affected by the food supplements.

Bakthavatsalam *et al.* (1994) reared adults of *M. boninens*is, *M. astur* (Bank) *C. carnea*, and *Apertochrysa sp.* on protinex mixture (protinex: yeast: honey: sugar in 1: 1: 1: 1 ratio by volume), 50% honey and water, and castor pollen.

A method for successive rearing of chrysopids including *M. boninensis* on eggs of *T. castaneum* (larval diet) and on a 2:3 mixture (by weight) of commercially available yeast autolysate (AY-65 or Amber BYF Series 100) and honey (adult diet) was established by Kubota and Shiga (1995).

Shivankar and Singh (1998) tried different combinations of honey, protinex and fructose prepared in water solution supplemented with pollen. They found that the best combination as adult food was 50% honey solution fortified with 40g protinex and 70g fructose supplemented with sunflower pollen which gave the highest egg laying (209 eggs) per female at 24±1°C and 65±5 % RH.

Tesfaye and Gautam (2002b) working on the chrysopid, *C. carnea* reported that adult food supplements influenced oviposition period, postoviposition period and fecundity significantly, while preoviposition period and longevity were not affected. Maximum eggs/female (1245) were laid when adults supplemented with baker's yeast granules + 50% honey followed by baker's yeast granules + 50% honey + castor pollen (1069) and castor pollen + 50% honey (450) as compared to control, *i.e.* (80). Productive age was also affected.

2.11 Effect of Continuous Rearing

In augmentation biological control maintaining the quality of the mass produced bio-control agent is a very important aspect. Normally insects kept in mass culture for long time are known to deteriorate in biological and behavioural attributes (Mackauer, 1972; Jones *et al.*, 1978).

Evidence of physiological deterioration among individual insects in cultures may be expressed as delayed maturation, increased mortality, and reduced fecundity (Mackauer, 1972). Boller (1972) suggested that selective pressure and conditioning associated with mass rearing might alter the behaviour of the organisms produced to the extent that they would not function well in field release studies.

However, no previous work has been done on the effect of continuous rearing on the biological attributes of *M. boninensis*. Nevertheless, a lot of work was done on other chrysopids like *C. carnea* which is extensively mass-produced all over the world for augmentation biological control of agricultural pests.

It was reported by Jones *et al.* (1978) in three strains of *C. carnea* kept in mass culture for 2, 15, and 43 generations fecundity, longevity, feeding, searching ability decreased as the number of generations in mass culture increased; while the developmental time increased. They concluded that insects intended for field release need not and should not be held in mass culture for more than 6 generations.

Gautam (1994c) working on *C. carnea* found that axenic rearing of larvae on frozen eggs of *C. cephalonica* revealed reduction in fecundity as well as acceptability of aphid prey by the end of 20th generation. However, he found that these parameters could be maintained by providing aphid prey to the aphid lion after 10th generation of axenic rearing on *C. cephalonica* eggs.

Hegde and Kulkarni (2005) reared a chrysopid predator, *C. carnea* up to 24th generation in mass on eggs of *C. cephalonica*. They observed slow decline in characters especially per cent hatchability and fecundity from 1st generation to 24th generation. However, there was no marked improvement in characters studied when larvae were fed on *A. gossypii*, *H. armigera* eggs and on combination of both of these, after 24 generations of rearing on *C. cephalonica* eggs.

2.12 Field Releases

Lee and Shih (1981) in a field experiment in Taiwan, released populations of *M. boninensis* and the psyllid, *P. psylloptera* into field cages containing mulberry plants. They found that the release of four 1st instar chrysopid larvae to an initial biomass index of 158 pest individuals was the best tactic for suppressing the pest population. Within 4-5 days the results suggested that the chrysopid was a good agent for the biological control of the psyllid in the field.

An experiment on field releases of eggs, first instar larvae or adults of *M. boninensis* against the citrus blackfly, *A. woglumi* on Nagpur mandarins at Nagpur, Maharashtra, India, revealed that all biological control treatments were significantly superior over the untreated control. Amongst releases of eggs, first instar or adults of

M. boninensis, releases of one and two pairs of adults were superior to the different levels of eggs or larvae, with per cent reduction in the population of *A. woglumi* of 34.25 and 40.00%, respectively (Kolhe *et al.*, 2003).

Jalali *et al.* (2003) reported that the chrysopids, *C. carnea* and *M. boninensis* have been selected for mass production and release against different crop pest species in India. Normally, the dose is 10,000 to 20,000 first instar larvae per hectare per release and two releases are needed. The dose varies according to the pest load and the predator load in the field where releases are to be made.

Ingole *et al.* (*2005*) released *M. boninensis* (at 2, 4 and 6 eggs and 2, 3 and 4 first instar larvae per shoot) thrice, against citrus blackfly, *A. woglumi* at an interval of 15 days on 'Nagpur' mandarin in Nagpur, Maharashtra, India. Amongst various dosages/ stages of *M. boninensis*, the release of 6 and 4 eggs per shoot recorded 36.72 and 34.65% cumulative reduction in *A. woglumi* population and was found to be more effective than the other dosages.

2.13 Mass-multiplication of the Prey

2.13.1 *C. cephalonica*

Shazali and Smith (1986) studied the effect of temperature and relative humidity on multiplication of *C. cephalonica* reared on sorghum grains in Sudan under laboratory conditions. They found that the optimum conditions were 30°C and 60-80% RH.

Etman *et al.* (1988) studied the development of *C. cephalonica* in Egypt on whole wheat flour at 28°C and 65%RH in the laboratory. The development from first instar larvae to adults took 40.9 and 43.5 days for males and females, respectively. Adult longevity was 9.1 and 7.0 days for mated and virgin males; 8.3 and 8.0 days for mated and virgin females, respectively. Virgin females laid more eggs than mated ones; 220.9 eggs for virgin and 196.0 eggs for mated ones.

Peng and Chen (1989) used whole or crushed grains of sorghum, brown rice, maize and other additives to prepare a range of media for rearing *C. cephalonica.* Results showed that larvae reared on crushed grain developed faster and had a higher reproductive potential than those fed on whole grain. The greatest egg yield was obtained when

C. cephalonica was reared at a density of 500 eggs/100g of crushed grain, with brown rice giving the best results, followed by sorghum and maize, in that order. The addition of 5% syrup, 3% glycerine, 5% dextrose or glycerine with syrup to crushed brown rice increased egg yield further.

Jalali and Singh (1992) worked out the optimum egg ratio per kg of sorghum grain for mass-rearing *C. cephalonica* which was determined based on grain utilization and adult emergence. They found the optimum number of eggs was 1500/kg grain. During the winter months (24±1°C), peak emergence occurred after 100-130, days whereas during the summer (29±1.5°C), peak emergence occurred after 61-90 days.

Kumar and Shenhmar (2001) evaluated different cereal grains *viz.*, maize, rice sorghum and wheat as feeds for *C. cephalonica* at different levels of moth eggs per kg. They found that the life cycle of *C. cephalonica* was shorter and fecundity and female progeny production were higher when reared on maize. Charging one kg of maize with 1500 eggs was found to be optimum for successful mass production. The authors also found that maximum production of eggs (10.90-11 cc. per kg) was on sorghum and maize

Medina and Cadapan (1982) reported that the main problems of rearing *C. cephalonica* were a braconid ectoparasite of the larvae, bacterial and fungal diseases, mites (some of which were grain pests and others preyed on the eggs of *C. cephalonica*) and competition for food by *Tribolium* sp.

2.13.2 *T. castaneum*

In laboratory studies on the life-cycle of *T. castaneum* in India, particular attention was paid to metamorphosis. The egg stage lasted 4-6 days, and the larval stage, which included 6-8 instars (normally 7) lasted 18-19 days at 30°C and 70% RH in the laboratory (Pajni and Virk, 1982).

Lopez (1985) reported that the generation time from egg to adult was 82.44 days and adult longevity was over 5 months when the insect was reared at laboratory conditions of 21°C and 65-70% RH.

Shazali and Smith (1986) studied the biology of *T. castaneum* on sorghum under laboratory conditions in Sudan. They reported that the optimal conditions for

multiplication of the beetle were 35°C and 60-80%RH. Lower humidity (40-50%RH) had a small adverse effect on the biology of the beetle.

2.14 Cost of Production

Tauber *et al.* (2000) reported that commercialization of natural enemies and increasing their use in pest management present applied entomologists and ecologists with formidable challenges. A response to these challenges requires: reducing the cost of mass-rearing and manipulating natural enemies, improving the success rate and predictability of biological control procedures, and demonstrating effectiveness, ecological benefits and safety of biological control under commercial conditions.

The cost of production is an important factor in augmentation biological control. Therefore, for the commercial production of *M. boninensis* the cost of the laboratory host should be economically feasible. Hitherto, no literature is available on the cost of mass-production of *M. boninensis* in the laboratory.

Viji and Gautam (2005b) reported that the cost of production of the chrysopid, *C. carnea* was dependent on the cost of production of prey used. They estimated the cost of production of 1,000 eggs of *C. carnea* to be Rs 7.16, Rs 3.68 and Rs 7.06 when its larvae were reared on *C. cephalonica* eggs, *T. castaneum* larvae and *D. melanogaster* larvae, respectively. They attributed the lower cost of production on *T. castaneum* larvae to: less amount of larval diet required, low mortality during developmental stages and emergence of highly fertile adults.

MATERIALS AND METHODS

The current study was carried out at the Plant Health Clinic, Division of Entomology, Indian Agricultural Research Institute (IARI), New Delhi which is located at a latitude of 28° 35' N, longitude of 77° 22' E and an altitude of 227 meters above sea level. A detailed account of materials used and methods adopted in the study are given in this chapter.

3.1 Mass Culturing of the Predator, *Mallada boninensis*

3.1.1 Maintenance of the stock culture

Nucleus culture of *M. boninensis* was obtained from National Research Centre for Citrus (NRCC), Nagpur, Maharashtra, India, as a consignment of cocoon and egg stages (28 cocoons and 50 eggs). Hatchability of the eggs was very low but the cocoons were viable and good enough to establish the culture. This stock was considered the parental generation.

The culture of *M. boninensis* was maintained in the laboratory by using standard procedure set by Gautam (1994b and 1994c). Adults were transferred to jars (21cm height, 18 cm dia.) and fed on 25% honey solution and castor, *Ricinus communis* L. or ganja, *Cannabis sativa* L. pollen grains. The jars were covered with black markin cloth and kept in BOD incubator at 26±1°C, 65±5% RH and 12:12 [L: D] hr. Females laid stalked eggs on the cloth which was changed daily and kept for hatching. Neonate larvae were transferred individually into small vials and fed on *Corcyra cephalonica* eggs. Food was added whenever needed till cocoon formation. Development was observed daily till adult emergence. Newly emerged adults were then transferred to new jars containing adult food supplements and the same cycle was continued. Thus, the predator culture was maintained.

Starting from the parental generation of *M. boninensis* on *C. cephalonica* eggs, another set was maintained in the same way on larvae of *Tribolium castaneum.*

3.1.2 Sex differentiation in *M. boninensis* imago

To have a reliable method for sex differentiation before or at the time of adult emergence is important for studies comprising pairing of male and female to follow their biology. It is also essential for determining the sex ratio of the population.

Therefore, observations were made to study the differences in the morphology of the last two abdominal segments in newly emerged (0-24 hr. old) imago. Close observations using a lens, 5X or a binocular microscope on the ventral side of the last two abdominal segments of each individual revealed that there are clear morphological differences. Accordingly, a batch of adults was divided into two groups A and B on the bases of the following features.

Group A

- The posterior end of the abdomen blunt (truncated).
- Presence of ventral longitudinal slit on the last abdominal segment.
- Last two abdominal sternites (8^{th} and 9^{th}) are separated (intersegmental line prominent).

Group B

- The posterior end of abdomen sharply tapering and pointing backward (clear from ventral side).
- No ventral longitudinal slit on the last abdominal segment.
- Sternites of the last two abdominal segments (8^{th} and 9^{th}) united (intersegmental line not prominent).

Depending on these features, 10 individuals from each group were kept individually in adult rearing glass tubes, provided with adult feeds (25% honey solution and pollen grains) and kept in the BOD at the normal rearing conditions. Daily observations were made for further development *i.e.* changes in the size of abdomen and egg laying.

3.1.3 Preparation of pollen grains

Pollen grains of castor, *R. communis* or ganja, *C. sativa* were used as adult feed supplement based on their seasonal availability. Normally, castor flowers were available during the period (mid September to March), while *Cannabis* flowers from April to August.

Flowers were collected from the field, cleaned, then spread in glass dishes and allowed for overnight to shed the pollen grains. After that the material was sieved gently using a fine cloth to separate the pollen grains. The pollen grains were collected in small glass vials, which could be stored in the fridge and used at need (Plate 1).

3.1.4 Laboratory conditions

All the experiments conducted on *M. boninensis* as well as maintaining its culture were carried out at laboratory conditions of 26±1°C, 65±5% RH and 12:12 [L: D] hr. in BOD unless otherwise mentioned in specific experiment.

3.2 Exploration of Suitable Prey

Studies were conducted to explore the acceptability and suitability of different insect species as potential laboratory prey for the larva of *M. boninensis*; depending on their effects on survival, development and other biological attributes of the predator. Efficient mass production of insects requires minimum time of developmental stages, maximum egg viability and a high level of adult emergence and fecundity (Jones *et al.*, 1978). The prey insects *viz.*, *C. cephalonica*, eggs; *Dysdercus koenigii* Fabricius, eggs; *Lipaphis erysimi* Kaltenbach, nymphs and adults; *Maconellicoccus hirsutus* (Green), ovisacs and nymphs; *Spilosoma obliqua* Walker, larvae; *T. castaneum,* larvae; *T. castaneum,* pupae and *Trogoderma granarium* Everts, larvae were used for the study.

3.2.1 Mass culturing of the prey

Mass culturing of the prey insects was done in order to have a continuous supply of insects for conducting various experiments on screening of suitable prey for *M. boninensis* larvae and to provide food for the predator culture. The above mentioned insects were cultured and kept in the laboratory.

Plate 1. Preparation of castor pollen grains

3.2.1.1 *Corcyra cephalonica* Stainton (Lepidoptera: Pyralidae)

C. cephalonica was reared following the procedure described by Gautam (1994a). Larvae of *C. cephalonica* were reared on a mixture of broken sorghum and maize grains. The grains were sterilized at 100°C for 3 hours to kill all stages of pests associated with the grains. Two grams of dried yeast powder were added per kg of grain to enhance the nutritive value. About 0.25cc (approximately 5,000 eggs) of *C. cephalonica* were sprinkled in jars (18 cm dia. and 21 cm height) containing 2.5 kg of food material and kept for development at room conditions. After egg hatching the larvae started feeding on the grains and pupated in silken cocoons. The moths started emerging from 30th day onwards, which continued up to 90 days.

Emerged adult moths were collected manually with the aid of a glass tube and transferred to an oviposition cage, which was a one liter capacity glass jar. The bottom end of the jar was fitted with 40-mesh size wire gauge which inturn was placed in a Petri dish. The top end of the jar was covered with a markin cloth and secured tightly by a rubber band. The moths started laying eggs after 3 days. Every morning eggs were collected; by shaking the oviposition jar and tapping it against a Petri dish. Scales were blown off and eggs were cleaned by passing through 15, 30 mesh sieves. Eggs were killed by exposing to freezing temperature in a refrigerator and then cold stored in the refrigerator for further use up to at most two weeks (Jalali *et al.*, 2003).

3.2.1.2 Tribolium castaneum Herbst (Coleoptera: Tenebrionidae)

T. castaneum culture was maintained in plastic jars (18cm dia. and 21cm height) containing wheat flour. The jars were covered with cloth secured by rubber bands and the culture was kept at 30±1°C and 65±5% RH in BOD.

Adult beetles were released in wheat flour and left to lay eggs for two days. Then the flour was sieved to remove adults and they were transferred to a new jar with fresh wheat flour to lay eggs and continue the same cycle. So, we could have a series of jars containing different stages of development at any point in time. This process was done for easy separation of equal age and size larvae at the time of harvest.

In this way the stock of adults can continue laying eggs up to 2-3 months then to be replaced by a newly emerged stock of adult beetles. Full grown larvae were harvested after 18-19 days while pupae 23-25 days from the date of releasing the adults. The

beetle's larvae or pupae were normally separated by passing the flour through 45 size mesh, cleaned by using a blast of air, put in air tight containers, freeze killed and used for feeding *M. boninensis* larvae.

3.2.1.3 *Trogoderma granarium* Everts (Coleoptera: Dermestidae)

T. granarium was reared on wheat grains in glass jars (15cm dia., 18cm height). The grains were sterilized for four hours at 60°C in hot air oven and then allowed to cool for overnight. The grains were stored in air-tight glass bottles to avoid any possible infestation. Newly emerged adults were released in the glass jar containing 500g of wheat grains. Then the culture was maintained at a temperature of 30±1°C and 65±5% RH in BOD.

Larvae became fully grown in 25-30 days. Larvae were separated by spreading the grains on a piece of cloth for 1-2 minutes, then pouring the grains back into the jar. The larvae normally adhere to the cloth which were scraped and collected into a plate using a brush. The larvae were then stored in freezer for feeding of *M. boninensis* larvae. When larvae were not removed, adults started emerging from 40th day onwards. Adults were removed and transferred to new jars containing sterilized wheat grains to continue the perpetuation of the culture.

3.2.1.4 *Spilosoma obliqua* Walker (Lepidoptera: Noctuidae)

Eggs of *S. obliqua* collected from castor field served as a source of culture. After hatching of eggs, neonate larvae were transferred to tender castor leaves for feeding in plastic jars covered with cloth and secured by rubber bands. Later instars were fed on mature castor leaves till pupation. Pupae were separated and kept in Petri dishes placed in a jar for adult emergence. Adults were provided with honey solution (50%) for feeding and folded papers were provided for egg laying, since adult preferred hidden areas. The culture was maintained in the laboratory at 27±1°C and 70% RH. Larvae, 2nd-3rd instars were collected regularly and stored in freezer for feeding *M. boninensis*.

3.2.1.5 Red cotton bug, *Dysdercus koenigii* Fabricius (Hemiptera: Pyrrhocoridae)

Adults of *D. koenigii* were collected from cotton field and reared in the laboratory at 30±1°C and 65±5% RH in plastic jars (18cm dia. and 21cm height). Cotton seeds soaked in water for overnight were sprinkled in the jar as food source for the adults.

Eggs were laid in a group among the cotton seeds. Eggs were collected daily, freeze killed and stored for studying acceptability and suitability as prey for larvae of *M. boninensis*.

3.2.1.6 Grapevine mealybug, *Maconellicoccus hirsutus* (Green) (Hemiptera: Pseudococcidae)

The grapevine mealybug was maintained on germinating potato tubers kept in jars (18cm dia., 22cm height) at 26±1°C and 65±5% RH in BOD incubator (Gautam,1996). Ovisacs and nymphs were collected regularly and used as prey for larvae of the predator.

3.2.1.7 Mustard aphids, *Lipaphis erysimi* Kaltenbach (Hemiptera: Aphididae)

L. erysimi was used as field prey. Adults and nymphs were collected daily from mustard field and used as feed for the larvae of *M. boninensis*.

3.2.2 Screening of the preys

Studies of rearing *M. boninensis* were carried out at laboratory conditions of 26±1°C, 65±5%RH and a photoperiod of 12:12 [L: D] hr. in BOD by using standard procedure described by Gautam (1994b). For each host 51 (17x3 replications) newly hatched (0-24 hr. old) larvae of *M. boninensis* were separated and confined individually in small glass tubes (vials) in which the respective preys were provided. Each larva was assigned a serial number; survival and development of different stages were followed. The different preys were normally given ad lib on alternate days. Daily observations were taken to record the acceptability of prey, development and mortality of different stages. On preys where the development of immature stages of the predator was completed, adult parameters were also followed.

Soon after adult emergence, male and female were differentiated according to the morphology of the tip of the abdomen. To ensure proper mating a group of males and females emerged on the same day were pooled together for three days in a plastic cage (18 cm dia. and 21cm height) covered with black cloth and provided with 25% honey solution, and pollen grains. After the three days, 6 pairs of adult (male and female each) for the predator reared on each prey were separated in glass tubes (4.0 cm dia. and 7.0 cm height) covered with black cloth. Honey solution and pollen grains were provided

as adult food. Daily observations were made to record egg laying and mortality of adults. On alternate days, the tubes were changed along with addition of fresh pollen and honey solution. Preoviposition, oviposition, postoviposition periods, adult longevity and fecundity were calculated. Depending on these parameters promising suitable preys for mass production of *M. boninensis* were selected for further investigations.

3.3 Effect of Continuous Rearing on Biological Attributes

Evidence of physiological deterioration among individual insects in cultures may be expressed as delayed maturation, increased mortality, and reduced fecundity (Mackauer, 1972). It was reported by Jones *et al.* (1978) that insects intended for field release need not to be held in mass culture for more than 6 generations. Therefore, rearing on two promising preys (larvae of *T. castaneum* and eggs of *C. cephalonica*) was carried up to 11 generations to evaluate the effect of continuous rearing on each of them on the performance of biological attributes of *M. boninensis*.

As mentioned above 51 neonate larvae of the predator, arranged in 3 replications (3x17) for each selected host in each generation were separated and confined individually in small vials and provided with the respective prey offered ad lib until cocoon formation.

Twelve pairs of the adult predator were separated for each host as mentioned above (see exploration of suitable prey). Observations were taken to record the following:

- Developmental time [egg incubation period, period of different instars, collective prepupal and pupal (cocoon) periods]
- Weight of cocoon (mg)
- Mortality in different stages (%)
- Sex-ratio (M : F)
- Fecundity of adult (eggs)
- Longevity of adult (male and female) (days)
- Preoviposition, oviposition and postoviposition periods (days)
- Egg hatchability (%)
- Wing expanse of adult (mm)

Experiments were carried out at laboratory conditions of 26±1°C, 65±5%RH and a photoperiod of 12:12 [L: D] hr. in BOD.

3.3.1 Egg hatchability and incubation period

To determine the hatching per cent and incubation period 51 (17x3 replications) newly laid (0-24 hr) eggs were chosen randomly, during the 2nd week of adult age in each generation. The stalks of eggs were cut off by means of a fine pair of scissors then eggs were transferred individually into small vials (6.5 cm height, 1 cm dia.), plugged with cotton wool. Observations were taken at 24 hours interval for hatching. The period between date of oviposition and date of hatching was considered as the incubation period. Average incubation period and per cent hatchability were calculated and recorded.

3.3.2 Larval parameters

To study larval parameters, 51 newly hatched larvae were transferred to small glass vials; each larva was assigned a serial number and fed on their respective preys. Observations on moulting and mortality were recorded daily. Moulted skin (exuvia) was taken as an index for completion of one stadium. Likewise, the duration of each instar from eclosion to cocoon formation was carefully noted for the predator on each of the two preys for different generations. The time period between hatching of eggs and cessation of larval feeding was taken as total larval period. Mortality of grubs during different instars, in different generations on each prey was calculated and compared.

3.3.3 Pupal (cocoon) parameters

The time from cessation of larval feeding to shedding of last instar cuticle (formation of pupa) is the prepupal (pharate pupa) duration (Richards and Davies, 1977). But, in chrysopids shedding of the last instar's cuticle occurs inside the cocoon and it can not be ascertained for each and every individual unless it is dissected. The period between cocoon formation and emergence of adult moth is considered as the cocoon period. So, here we used the term cocoon to imply prepupal and pupal stage collectively. Cocoons were observed daily for the emergence of adults. Mortality during collective prepupal and pupal (cocoon) stage was also recorded. In each generation, twenty one (7x3 replications) cocoons of the predator reared on each prey were taken 1-2 days after cocoon formation, separated gently from the surface of the glass tubes or cotton plugs, cleaned from prey debris and their weights were recorded using an electronic balance [SARTORIUS, model: 1712 mp8; Monopan, sensitive to 0.001mg (Made in Germany)].

To determine the duration of prepupal stage 25 cocoons were dissected one day after cocoon formation and observed daily for further development. Shedding of the cuticle of the last larval instar was considered the end of prepupal stage (pharate pupa) and starting of pupal stage. The time lag between the larva ceased feeding, became sluggish in movement to shedding of cuticle was recorded as the prepupal period. Moreover, some larvae during different generations pupated without formation of cocoons; their development was also recorded to note the prepupal and pupal periods.

3.3.4 Adult parameters

3.3.4.1 Longevity

Preoviposition period was considered as the period from the time of emergence of the female imago to the time the first egg was laid. The time elapsed between the start of egg laying to the last egg laid by the female was considered as oviposition period. Postoviposition period was noted as the time period between the last egg laid and death of female. The number of days the adult survived from emergence out of cocoon to death was taken as adult longevity or life span for either male or female.

3.3.4.2 Fecundity

Egg counts of the adult female were made at 24 hours interval. Total number of eggs laid/female during its lifetime was recorded as female fecundity. Average fecundity in each generation on either prey was calculated. Average fecundity trend on weekly basis was also summed up for each generation on either prey.

3.3.4.3 Sex ratio

Sex ratio was recorded by counting the total number of female and male imagoes emerged out in each generation on either prey.

3.4 Construction and Analysis of Life Tables

The cohort life table gives the most comprehensive description of the survivorship, development and reproduction of a population, and as such, is fundamental to both theoretical and applied population ecology (Chi and Yang, 2003).

The cohort (age-specific) life and fecundity tables of *M. boninensis* were constructed in the laboratory on the most promising two preys (larvae of *T. castaneum*

and eggs of *C. cephalonica*) so as to estimate the comparative overall effects of them on the survival and growth rate of the predator population. The life tables of the predator were constructed for generation number eight on each of the two preys.

A group of 100 freshly laid eggs of *M. boninensis* reared on each of the two hosts were separated individually in small vials and observed daily for subsequent development and survival. After egg hatching the larvae were fed on the respective preys. Daily observations on survival and development were taken and recorded till emergence of adults.

Adults emerged on the same day were pooled in plastic jars for three days to ensure proper mating; then each male and female were kept in pairs and provided with adult food as mentioned above in glass tubes (4.0cm dia., 7.0cm height). Fecundity and mortality were followed daily for each pair till death of the last adult. The life and fecundity tables were constructed as described by Andrewartha and Birch (1954), Southwood (1966) and Jervis *et al.* (2005) with the following columns:

i. Life table

x pivotal age for the age class in units of time

l_x numbers surviving at the beginning of age class x

d_x numbers dying during the age interval x

L_x number of individuals alive between age x and $x+1 = (L_x + L_{x+1})/2$

T_x total number of individuals X age units beyond the age $x = L_x + L_{x+1} + L_{x+2} + \ldots L_n$

e_x expectation of life remaining for individuals of age $x = T_x/l_x$

ii. Fecundity table :

x pivotal age for the age class in units of time

l_x number of females surviving at the beginning of age class x

(given as fraction of 1.0)

m_x number of female eggs laid by age class x

$l_x m_x$ total number of female eggs laid in age class x

The following statistics were estimated:

- Survivorship in each age group
- Gross reproductive rate (GRR) = Σm_x
- Net reproductive rate (R_0) = $\Sigma l_x m_x$
- Approximate generation time (T_c) = $\Sigma x l_x m_x / \Sigma l_x m_x$
- Capacity for increase (r_c) = $\log_e R_0 / T_c$
- Intrinsic rate of natural increase (r_m)

  was substituted in the equation $\Sigma e^{-rmx}\ l_x m_x = 1$
- Finite rate of natural increase (λ) = e^{rm} = antilog_e^{rm}
- Mean generation time (T) = $\log_e R_0 / r_m$
- Doubling time (DT) = $\log_e 2 / r_m$

3.5 Standardization of the Prey, *T. castaneum*

3.5.1 Optimization of density of *T. castaneum* adults/unit weight of wheat flour

Adults and larvae of *T. castaneum* are of cannibalistic nature if surplus food is not provided for them (Park *et al.*, 1974). So, the optimum number of adult beetles required to get maximum number of full grown grubs with good size and total biomass per unit weight of wheat flour was worked out.

For this purpose10, 20, 60, 100, 140, 200, 260, 400 and 500 adults (unsexed) were released in plastic containers in which 100g of wheat flour passed through 45 size mesh was provided. Three replications in a CRD were maintained for each treatment. The experiment was kept at 30±1°C and 65±5%RH in BOD. After 2 days, adults were removed by sieving through the 45 size mesh.

From day 15th onwards, daily samples of the flour were taken so as to observe the growth and development of the larvae. When larvae reached full grown size and few start pupating, the flour was sieved and larvae were separated, cast skins were blown off and other debris removed. The numbers and total biomass of larvae in each case were recorded. The average weight of larva in each experimental unit was calculated

by dividing the total biomass by the corresponding number of larvae. Also the number of days required for larvae to become full grown was recorded. Means of different treatments were compared.

3.5.2 Quantification of *T. castaneum* adults by weight or volume

It is difficult to count large numbers of a small and active moving insect like *T. castaneum.* Therefore, to estimate the numbers through a measurable volume or weight, can be more practical in saving effort and time. For this purpose, *T. castaneum* adults about one month old were separated from the flour through sieving, cleared from all other stages as well as debris. Using measuring cylinder, a sample of seven volumes (1ml each) of the adult beetles was measured. Samples were replicated three times with month interval. The number of adults in each sample unit was counted and recorded. Average and standard error were calculated. Likewise, so as to relate the number of adults to their weight; a sample of seven units (0.1g each) was weighed using a sensitive electronic balance and the number of adults in each unit was counted. Average and standard errors were calculated.

3.5.3 Optimization of *T. castaneum* larvae as prey for *M. boninensis*

All these studies were carried out at laboratory conditions of 26±1°C, 65±5% RH and 12: 12 [L: D] hr in BOD incubator. The following parameters were taken for evaluation in different experiments:

- percent survival from 1st instar to imago
- Developmental period (from hatching to emergence of imago)
- Cocoon weight

3.5.3.1 Standardization of prey age

Studies were carried out to determine the most suitable age of the prey (*T. castaneum* larvae) for the consumption and development of the predator. For this purpose larvae of *T. castaneum* were harvested at two different ages; full grown larvae (18-19th day from release of adults) and younger larvae (12-13th day from release of adults) at the conditions mentioned above for rearing *T. castaneum*.

On each age group 30 (10x3 replications) neonate larvae of *M. boninensis* were reared in small glass vials. The larvae of *T. castaneum* were harvested, freeze killed and offered ad lib on alternate days. Daily observations were taken on development and mortality till the emergence of the adult. The experiment was carried out on generation no.12 continuous rearing on *T. castaneum* larvae.

3.5.3.2 Standardization of numbers

Full grown larvae were found more suitable than younger ones. Therefore, so as to determine the optimum number of full grown *T. castaneum* larvae required per predator larva to complete its development; an experiment was conducted with 6 feeding regimes (treatments) and 3 replications each, as follows:

* Regime-1, each predator larva was given one *T. castaneum* larva/day till cocoon formation (1,1,1,.....).
* Regime-2, each predator larva was given one *T. castaneum* larva/day for the first 3 days, then 2 larvae/day till cocoon formation (1,1,1,2,2,.....).
* Regime-3, given one *T. castaneum* larva/day for the first 3 days, then 2 larvae/ day for the next 3 days, then 3 larvae/day till cocoon formation (1,1,1,2,2,2,3,3....).
* Regime-4 given (1,1,1,2,2,2,4,4.....).
* Regime-5 given (1,1,1,2,2,2,5,5.....).
* Regime 6 given (2,2,2,3,3,3,4,6,6.....).

For each treatment (regime)30 neonate *M. boninensis* larvae were maintained. The predator larvae were kept individually in small glass vials assigned serial numbers and fed daily on the respective regime. The larvae of *T. castaneum* were harvested daily, freeze killed and offered. The experiment was conducted on generation 12 continuous rearing on *T. castaneum* larvae. Daily observations were taken on development, activity, consumption of food, mortality etc., till pupation and emergence of adults. The above mentioned parameters were taken to evaluate the different regimes:

3.5.3.3 Standardization of feed offering intervals

So as to reduce the cost of handling; a study was carried out to test the effect of the interval of offering the prey (full grown, freeze killed *T. castaneum* larvae) on development and survival of *M. boninensis*. For this purpose six treatments (feed offering intervals) were tested. Each treatment involved 30 newly hatched larvae of *M. boninensis*. The treatments are:

Treatment	Feed offering intervals	No. of *Tribolium* larvae given/larva/day (D)								
		D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9
T1	daily offering	2	2	2	3	3	3	5	6	6
T2	One day interval	4	-	5	-	6	-	10	-	7
T3	Two days interval	6	-	-	9	-	-	17	-	-
T4	Three days interval	9	-	-	-	16	-	-	-	7
T5	Five days interval	16	-	-	-	-	-	16	-	-
T6	Given once (1st day)	32	-	-	-	-	-	-	-	-

`Full grown *T. castaneum* larvae were harvested in sufficient amount; freeze killed and kept in the chest of the refrigerator. The harvest was done on the same day of hatching of *M. boninensis* larvae needed to be used for the experiment. A fixed number of *T. castaneum* (32 larvae) was given for each predator's larva; once or in split doses according to the treatments mentioned above. As the prey consumption by the predator increases with increase in age (Lee and Shih, 1981; Mani and Krishnamoorthy, 1990; Kabissa *et al*, 1995) the numbers offered were varied according to age and interval used.

3.5.3.4 Storage of the prey and its effect on the predator

Storage of the host (prey) is sometimes essential for practical and economic mass-production of bio-control agents. Therefore, the storability and the effect of the stored prey on survival and development of the predator were studied.

To see the impact of frozen storage of *T. castaneum* larvae on the survival and development of the predator, full grown larvae of *T. castaneum* were harvested at different intervals, freeze killed and stored frozen in the chest of a refrigerator in air tight

containers. The harvests were synchronized so as to give different periods of storage (0 day, 7 days, 15 days, 30 days, 45 days and 60 days at the starting date of the experiment (first feeding day). This in addition to control treatment containing daily harvest of *T. castaneum* larvae freeze killed and offered fresh to *M. boninensis* larvae.

In each treatment 30 newly hatched larvae of the predator were used. The stored prey was offered daily from the respective labeled containers by taking the amount to be used in small plates and keeping the rest in the refrigerator. Daily observations were recorded on survival and development till emergence of adults.

3.6 Acceptability of Original Prey

To examine the effect of continuous rearing on factitious laboratory host (larva of *T. castaneum*) on acceptability of the predator for the original host an experiment was conducted. Two original hosts of *M. boninensis* were tested; these were mustard aphid, *Lipaphis erysimi* Kalt. and a mealybug, *Phenacoccus solani* Ferris infesting *Abutilon* plant.

On each of the two preys, 30 neonate *M. boninensis* larvae (progeny of generation 11 continuous rearing on *T. castaneum* larvae) were reared. The predator larvae were kept individually in small glass vials assigned serial numbers and fed daily on the respective host. The two hosts were collected from the field. Adults and nymphs of both hosts were offered for feeding. Daily observations were taken on feeding (acceptability), survival and development (suitability) of the predator on each of them.

3.7 Cost of Production

The cost of mass rearing the factitious host has a crucial effect on the cost of final saleable bio-control agent in a commercial mass production programme, which is essential for the success of any bio-control project. The cost of mass production of the predator on the best suitable prey, *T. castaneum* larvae and the traditional prey, *C. cephalonica* eggs was calculated following the method used by Jayaraj (1994).

The costs were placed under the subheadings, fixed cost and variable cost. The fixed cost includes depreciation on equipments, interest on fixed costs and annual rent. Variable cost includes working capital and interest on working capital. The current existing prices, obtained from the stores were used for the calculation.

3.9 Statistical analysis

Data obtained under various methods were tabulated and subjected to statistical analysis as per the requirements of the experiment. All the data generated were subjected to Analysis of variance using M-stat package. Significant (P= 0.05) treatment means were compared using critical difference which compares treatment means and interactions. Arc sin or square root transformations were made wherever necessary.

RESULTS

The present study is entitled **"Exploration of potential host for mass-production of green lacewing, *Mallada boninensis*"**. Different aspects of the study pertaining to screening of prey, effect of prey on the biological attributes of the predator, standardization of the prey and feasibility of mass-production were investigated. Results obtained in various experiments are presented in this chapter under the following heads:

4.1 Screening of a Suitable Host/Prey for *M. boninensis*

4.1.1 Parental stock

Table 1 shows the performance of the initial stock (Nagpur stock).

4.1.2 Acceptability of the prey

Results on acceptability of the prey are shown in Table 2 and Fig. 1. Two preys were not accepted at all; these were the eggs of the red cotton stainer bug, *Dysdercus koenigii* and the larvae of the moth, *Spilosoma obliqua.* All the predator larvae reared on them died during the first instar, likewise all the larvae reared on *Trogoderma granarium* larvae died during the larval period but, during different instars. Other five preys *viz.*, *Corcyra cephalonica* eggs, *Lipaphis erysimi* nymphs and adults, *Maconellicoccus hirsutus* ovisacs and nymphs, *Tribolium castaneum* larvae, and *T. castaneum* pupae were accepted by the predator but, they showed varied effects on survival and development of different stages of the predator.

4.1.3 Suitability of the prey

4.1.3.1 Survival of immature stages of *M. boninensis* on different prey species

The results on survival of immature stages of *M. boninensis* on the five accepted preys are presented in Table 2 and Fig. 1. Analysis of variance (ANOVA) for survival, from neonate larva to cocoon, from cocoon to adult and overall survival from neonate larva to adult showed highly significant difference.

Survival from neonate larva to cocoon was highest on *C. cephalonica* eggs (95.56%) and it was statistically at par with those reared on *T. castaneum* larvae (91.10%), while the lowest larval survival was in larvae reared on *T. castaneum* pupae (48.89%) followed by larvae reared on *L. erysimi* nymphs and adults (82.22%). It is also worth mentioning that 9.8% of the larvae reared on *L. erysimi* nymphs and adults failed to pupate, lived for 34-35 days and died as prepupae.

Table 1. Nucleus culture of *M. boninensis* received from NRCC, Nagpur

a - Eggs

Total No.	Hatchability		Larvae pupated		Adults emerged
	No.	%	No.	%	
46	7	15.22	4	57.14	4

b - Cocoons

Total No.	Adult emerged				
	No.	%	Males	Feamles	Malformed
28	18	64.29	7	10	1

c - Adults Longevity and total fecundity (average±SE)

Male longevity (days)	Female longevity (days)				Total fecundity (Eggs/ female)	Sex ratio (M : F)
	Pre-oviposition period	Ovi-position period	Post-oviposition period	Total longevity		
33.33±3.47	4.58±0.19	31.5±4.04	3.58±0.95	40±4.61	343±47.82	1:1.33

Values presented are average of 12 pairs of adult each.

Table 2. Acceptability of different prey species by larvae of *M. boninensis* and effect of prey on survival of immature stages of the predator

Prey species and stage	Acceptability of prey	% Survival neonate larva to cocoon	% Survival cocoon to adult	% Survival neonate larva to adult	Remarks
C. cephalonica egg	Accepted	95.56 (80.06)[a]	88.26 (70.24)[b]	84.44 (67.34)[a]	Suitable
D. koenigii egg	Not accepted	0.00 (0.70)[e]	-	0.00 (0.70)[d]	All died during 1st instar
L. erysimi nymph and adult	Accepted	82.22 (65.19)[c]	100.00 (90.05)[a]	82.22 (65.19)[a]	9.8% of larvae failed to pupate and died after 34-35 days as pre-pupae
M. hirsutus ovisac and nymph	Accepted	88.89 (70.77)[bc]	70.15 (56.10)[c]	62.22 (52.12)[b]	26% of adults were malformed
S. obliqua larva	Not accepted	0.00 (0.70)[e]	-	0.00 (0.70)[d]	All larvae died during 1st instar
T. castaneum larva	Accepted	91.10 (72.92)[ab]	87.73 (74.05)[b]	80.00 (63.68)[a]	Suitable
T. castaneum pupa	Accepted	48.89 (44.38)[d]	90.74 (75.52)[b]	44.00 (41.77)[c]	37% of larvae pupate without cocoons, 13.6% of adults were malformed
T. granarium larva	Poorly accepted	0.00 (0.70)[e]	-	0.00 (0.70)[d]	All larvae died before pupation but during different instars; some lived as larvae up to 22 days, prey unsuitable
SEm ±		**2.47**	**2.99**	**2.21**	
CD at 5%		**7.16**	**8.68**	**6.43**	
CD at 1%		**7.66**	**11.72**	**8.68**	

Values presented are means of 3 replications each; each replication is a mean of 17 neonate larvae at start; figures in parentheses are arc sin transformed values; - not applicable; means compared using CD at 5%; means followed by the same letter in the column are not significantly different from each other.

Cocoon survival was highest on *L. erysimi* (100%) and it was significantly different from all others ($P \leq 0.01$), while the lowest cocoon survival was observed on *M. hirsutus* ovisacs and nymphs (70.15), which was significantly different from others ($P \leq 0.05$). The other three preys were statistically at par.

Regarding overall per cent survival from neonate larva to adult, *C. cephalonica* eggs (84.44%), *L. erysimi* (82.22%) and *T. castaneum* larvae (80.00%) were at par but, significantly different from the other two. The lowest overall survival was exhibited by larvae reared on *T. castaneum* pupae (44.00%) followed by larvae reared on *M. hirsutus* (62.22%) nevertheless, the two were statistically different from each other.

4.1.3.2 Effect of prey species on larval period, cocoon period and cocoon weight

Results on the effects of the five accepted prey species and/or stages on larval period (days), cocoon period (days) and cocoon weight (mg) are presented in Table 3 and Fig. 2. Analysis of variance for the three parameters showed highly significant difference ($P \leq 0.01$).

Larval period was shortest (8.1 days) when larvae were reared on *C. cephalonica* eggs and it was significantly different from the other four preys; followed by *T. castaneum* larvae (9.47 days) and *L. erysimi* (9.60 days), the latter two were statistically at par. Larval period was longest on *T. castaneum* pupae (11.93 days) followed by *M. hirsutus* nymphs and ovisacs (11.23); the two were significantly different from each other.

Cocoon period was shortest on *C. cephalonica* eggs (9.63 days) followed by *T. castaneum* larvae (9.9 days); both were at par. Longest period for the cocoon was observed when larvae were reared on *T. castaneum* pupae (10.5 days) followed by *L. erysimi* (10.23 days) and *M. hirsutus* (10.13 days) and the three were not significantly different from each other (Table 3 and Fig. 2).

The highest cocoon weight was obtained from those whose larvae were reared on *C. cephalonica* eggs (10.86mg) but, it was statistically at par with those reared on *L. erysimi* nymphs and adults (10.57 mg) and those reared on *T. castaneum* larvae (10.32mg). The lowest cocoon weight (8.22mg) was obtained when larvae were reared on *M. hirsutus* followed by *T. castaneum* pupae (8.55 mg).

4.1.3.3 Effect of prey species on adult longevity and fecundity

Analysis of variance revealed significant differences ($P \leq 0.05$) among preys for total female longevity, fecundity, preoviposition and oviposition period, while no

Table 3. Average larval period, cocoon period and cocoon weight of *M. boninensis* reared on five different preys

Prey species and stage	Average larval period (days)	Average cocoon period (days)	Average cocoon weight (mg)
C. cephalonica egg	8.10[a]	9.63[a]	10.86[a]
L. erysimi nymph and adult	9.60[b]	10.23[b]	10.57[a]
M. hirsutus ovisac and nymph	11.23[c]	10.13[bc]	8.22[b]
T. castaneum larva	9.47[b]	9.90[ab]	10.32[a]
T. castaneum pupa	11.93[d]	10.50[c]	8.55[b]
SEm±	**0.22**	**0.15**	**0.27**
C.D. at 5%	**0.65**	**0.43**	**0.77**
C.D. at 1%	**0.88**	**0.58**	**1.04**

Values presented are average of 3 replications each

Each replication is an average of 10 observations in case of periods or 7 observations in case of cocoon weight

Means compared using CD at 5%

Means followed by the same letter in the column are not significantly different from each other.

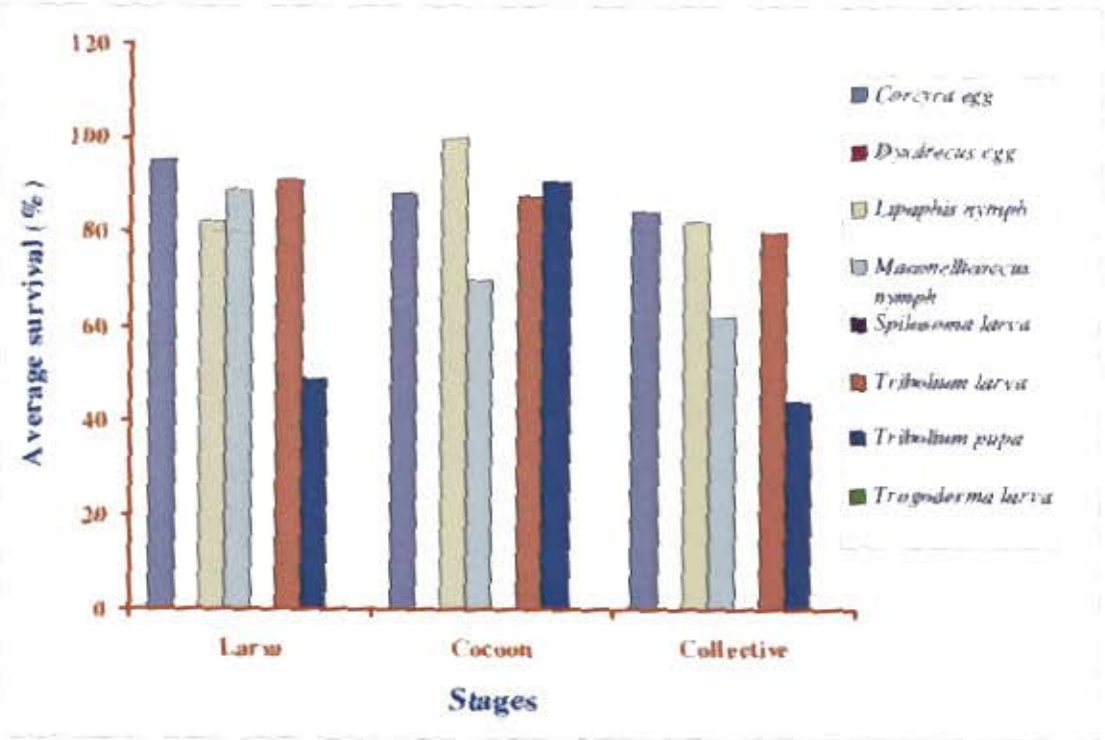


Fig. 1. Survival of immature stages of *M. boninensis* reared on different prey species

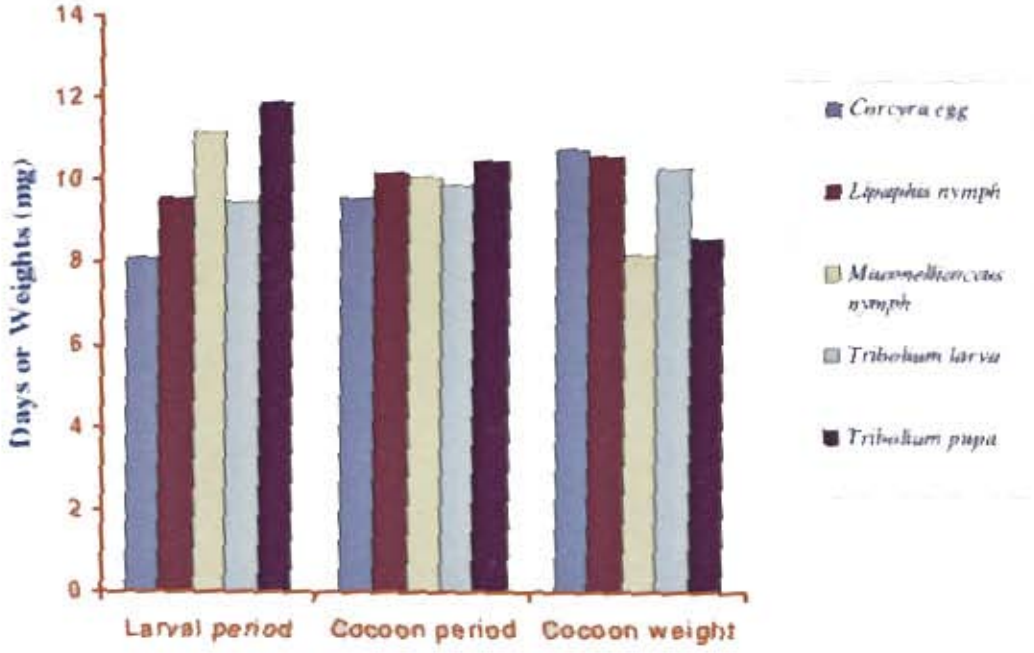


Fig. 2. Developmental period of immature stages and cocoon weight of *M. boninensis* reared on different prey species

significant differences were detected for male longevity and female postoviposition period (Table 4).

Average male longevity was highest on *C. cephalonica* eggs (43 days) and lowest on *T. castaneum* pupae (33.50 days). The longest female longevity of the predator was revealed by those reared on *C. cephalonica* eggs (57.67 days) and it was at par with those reared on *T. castaneum* larvae (46.17 days). The shortest female longevity was shown by insects reared on *T. castaneum* pupae (38.67 days), which was at par with those reared on *L. erysimi* (41 days). Preoviposition period was shortest on *T. castaneum* pupae (4.33 days) which was not significantly different from *T. castaneum* larvae (4.83 days). On the other hand the longest preoviposition period was on *L. erysimi* (6.17 days) which was at par with *C. cephalonica* eggs (6.00 days).

Oviposition period was longest on *C. cephalonica* eggs (48.00 days) which was statistically at par with *T. castaneum* larvae (39.00 days). Shortest oviposition period (31.33 days) was recorded on *T. castaneum* pupae followed by *L. erysimi* (31.67 days). For postoviposition period the treatment means ranged between 2.33 days for *T. castaneum* larvae and 3.67 days for *C. cephalonica* eggs and no significant difference among the four treatment means.

The highest fecundity was obtained on *C. cephalonica* eggs (652.17 eggs) followed by *T. castaneum* larvae (566.83 eggs) and *L. erysimi* (410.33 eggs) and the three were at par, while the lowest fecundity (387 eggs) was produced by *T. castaneum* pupae.

4.2 Continuous Rearing of *M. boninensis* on *C. cephalonica* eggs and *T. castaneum* larvae

Results on effects of rearing the predator, *M. boninensis* continuously on *C. cephalonica* eggs and *T. castaneum* larvae up to eleven generations are presented in the following paragraphs. The results are compiled in the form of, effects on survival and developmental period of immature stages, effects on longevity, fecundity, sex ratio of adult, and effects on cocoon weight and adult wing expanse.

4.2.1 Effect on mortality of immature stages of the predator

4.2.1.1 Collective immature mortality

The results on per cent mortality are presented in Table 5. The overall mean of generations on either of the two preys revealed that per cent collective (neonate larvae to adult emergence) mortality was significantly higher (30.21) for the stock reared as

Table 4. Average longevity and fecundity of *M. boninensis* reared on four different preys

Prey	Male longevity (days)		Female longevity (days)								Fecundity (eggs/female)	
			Pre-oviposition period		Oviposition period		Post-oviposition period		Longevity			
C. cephalonica egg	43.00	(6.42)	6.00	$(2.54)^{a}$	48.00	$(6.94)^{a}$	3.67	(1.89)	57.67	$(7.50)^{a}$	652.17	$(25.07)^{a}$
T. castaneum larva	36.50	(6.00)	4.83	$(2.31)^{ab}$	39.00	$(6.27)^{ab}$	2.33	(1.62)	46.17	$(6.81)^{ab}$	566.83	$(23.79)^{ab}$
L. erysimi nymph and adult	37.83	(6.14)	6.17	$(2.57)^{a}$	31.67	$(5.65)^{bc}$	3.17	(1.84)	41.00	$(6.42)^{b}$	410.33	$(19.99)^{ab}$
T. castaneum pupa	33.50	(5.74)	4.33	$(2.17)^{b}$	31.33	$(5.54)^{c}$	3.00	(1.82)	38.67	$(6.20)^{b}$	387.50	$(19.09)^{b}$
SEm±		**0.473**		**0.12**		**0.32**		**0.12**		**0.32**		**1.76**
C.D. at 5%		**NS**		**0.34**		**0.93**		**NS**		**0.93**		**5.12**
CD at 1%		**-**		**-**		**1.26**		**-**		**1.26**		**-**

Each value is an average of 6 replications (pairs of adults)

Values in parentheses are square root transformed

Means compared using CD at 5%

NS, Statistically not different at 0.05 level

Means followed by the same letter in the column are not significantly different from each other.

larvae on *C. cephalonica* eggs as against 25.38 for the stock reared on *T. castaneum* larvae.

Considering collective mortality in the same generation on the two preys; the mortality in all generations except the 1st generation (G_1) was higher on *C. cephalonica* eggs than on *T. castaneum* larvae and the difference in six generations (G_3, G_4, G_6, G_7, G_{10} and G_{11}) was significant. In G_1 the mortality was significantly higher on *T. castaneum* larvae.

Comparing different generations on the same prey; per cent collective mortality on *T. castaneum* larvae was lowest in G_7 (9.80) which was statistically at par with G_6 and G_{10}, while the highest mortality was observed in G_2 and G_3 (29.41 both) which were significantly different from all other generations. On the other hand for *C. cephalonica* eggs, the highest mortality (41.36%) was observed in G_3 and it was statistically at par with G_4, while the lowest mortality (13.73%) was observed in G_5 and it was statistically at par with G_1, G_6 and G_8.

4.2.1.2 Mortality in different stages

4.2.1.2.1 Egg mortality

Statistical analysis of variance for per cent egg mortality revealed significant difference ($P \leq 0.05$) for prey. The overall mean of generations on either prey for egg mortality was significantly lower on *T. castaneum* larvae than on *C. cephalonica* eggs. The mean values were 17.50 and 22.41 for the two preys, respectively.

Comparing the same generation on the two preys; in five generations (G_2, G_3, G_4, G_7 and G_8) out of the ten generations observed, the egg mortality was significantly lower on *T. castaneum* larvae than on *C. cephalonica* eggs, while in two generations (G_5 and G_{10}) mortality was significantly lower on *C. cephalonica* eggs. In three generations (G_1, G_6 and G_{11}) no significant difference was detected.

4.2.1.2.2 Larval mortality

Larval per cent mortality was significantly lower on *T. castaneum* larvae in six generations (G_2, G_3, G_4, G_6, G_7 and G_{11}), while the mortality was significantly lower on *C. cephalonica* eggs in four generations (G_1, G_5, G_8 and G_{10}) (Table 5). The overall mean of generations on either prey showed no significant difference between the two preys.

Highest per cent larval mortality (21.53) on *C. cephalonica* eggs was observed in G_3 which was statistically not different from G_2, G_4, G_6 and G_{11}, while the lowest per

Table 5. Generation wise mortality (%) of *M. boninensis* reared on *C. cephalonia* eggs and *T. castenum* larvae

Generation	Egg		1st Instar		2nd Instar		3rd Instar		Larval	
	Cc	Tc	Cc	Tc	Cc	Tc	Cc	Tc	Cc	Tc
G1	18.94 (25.59)^{b}	13.72 (21.66)^{b}	1.96 (4.68)*^{a}	3.92 (9.36)^{bc}	1.96 (4.68)	2.08 (4.83)	0 (0.70)	4.04 (9.51)	3.92 (9.36)*^{a}	9.80 (18.06)^{bc}
G2	13.72 (21.66)^{ab}	9.80 (14.97)*^{ab}	5.88 (1137)^{ab}	1.96 (4.60)*^{ab}	6.13 (11.37)	3.92 (9.36)	2.38 (5.17)	2.08 (4.83)	15.65 (22.61)^{b}	9.80 (16.05)*^{bc}
G3	19.61 (26.23)^{b}	7.84 (12.96)*^{ab}	11.76 (19.65)^{b}	9.8 (18.06)^{c}	6.83 (15.15)	4.31 (9.82)	7.02 (15.57)	2.2 (4.99)	21.53 (27.61)^{b}	13.68 (21.63)*^{c}
G4	23.53 (29.03)^{b}	5.88 (11.37)*^{a}	7.84 (16.05)^{b}	0 (0.70)*^{a}	0 (0.70)	3.92 (9.36)	0 (0.70)	1.96 (4.68)	7.84 (16.05)^{ab}	3.92 (9.36)*^{ab}
G5	7.84 (12.96)*^{a}	9.80 (18.07)^{ab}	1.96 (4.68)*^{a}	3.92 (9.36)^{bc}	1.96 (4.68)	2.08 (4.83)	0 (0.70)	0 (0.70)	3.92 (9.36)*^{a}	5.88 (14.04)^{bc}
G6	9.80 (14.97)^{ab}	9.80 (14.77)^{ab}	5.88 (14.04)^{b}	3.92 (9.36)*^{bc}	2.03 (4.83)	0 (0.70)	0 (0.70)	0 (0.70)	7.84 (16.05)^{ab}	3.92 (9.36)*^{ab}
G7	13.72 (21.05)^{ab}	7.84 (16.05)*^{ab}	5.88 (11.37)^{ab}	1.96 (4.68)*^{ab}	0 (0.70)	0 (0.70)	0 (0.70)	0 (0.70)	5.88 (11.37)^{a}	1.96 (4.68)*^{a}
G8	15.65 (23.02)^{b}	7.84 (13.38)*^{ab}	3.92 (17.36)^{b}	1.96 (4.68)*^{ab}	0 (0.70)	1.96 (4.68)	0 (0.70)	1.96 (4.68)	3.92 (9.36)*^{a}	5.88 (14.04)^{bc}
G10	9.76 (18.03)*^{a}	15.69 (23.26)^{b}	3.92 (9.36)^{ab}	5.88 (11.37)^{bc}	0 (0.70)	2.08 (4.83)	0 (0.70)	0 (0.70)	3.92 (9.36)*^{a}	7.84 (13.38)^{b}
G11	27.45 (31.58)^{b}	23.53 (28.91)^{b}	9.8 (18.06)^{b}	0 (0.70)*^{a}	4.30 (9.82)	5.88 (11.37)	4.45 (9.98)	0 (0.70)	17.53 (24.76)^{b}	5.88 (11.37)*^{ab}
Mean	**(22.41)**	**(17.50)***	**(11.86)**	**(7.16)***	**(5.05)**	**(5.91)**	**(3.07)**	**(2.87)**	**(15.59)**	**(13.20)**
CD. P. 5%	**4.172**		**3.780**		**NS**		**NS**		**NS**	
CD. G 5%	**NS**		**NS**		**NS**		**NS**		**7.990**	
CD. Int. 5%	**NS**		**NS**		**NS**		**8.288**		**NS**	

Cc., *C. cephalonia* eggs; Tc., *T. castenum* larvae; CD. P, CD Prey; CD.G, CD Generation; CD. Int., CD Interaction (PxG); Values presented are average of 51 observations (17x3 replications) each, in eggs and at start of 1st instar; Values between parentheses are arc sin transformed; *, value is significantly different for the stage in same generation (prey comparison generation wise); NS, F test not significant at 0.05 level.

Continued.....Table 5

Generation	Pupation failure		Cocoon		Malformed adult		Collective immature	
	Cc	Tc	Cc	Tc	Cc	Tc	Cc	Tc
G1	0 (0.70)^{a}	0 (0.70)^{a}	10.29 (18.47)^{bc}	6.53 (14.81)^{*ab}	2.08 (4.83)^{*ab}	6.82 (12.31)^{b}	15.69 (23.26)^{*ab}	21.57 (27.64)^{b}
G2	2.08 (4.83)^{*ab}	4.17 (9.65)^{b}	14.15 (21.71)^{c}	11.11 (19.27)^{b}	2.78 (5.59)^{*ab}	9.73 (10.24)^{b}	31.37 (33.98)^{c}	29.41 (32.78)^{c}
G3	4.79 (10.36)^{b}	0 (0.70)^{*a}	13.49 (21.24)^{bc}	9.36 (17.57)^{*b}	8.46 (13.85)^{b}	7.51 (12.87)^{b}	41.36 (39.91)^{d}	29.41 (32.78)^{*c}
G4	14.86 (22.60)^{c}	2.08 (4.83)^{*ab}	25.09 (30.01)^{d}	10.56 (18.80)^{*b}	0 (0.70)^{*a}	2.38 (5.17)^{ab}	41.18 (39.91)^{d}	21.57 (27.64)^{*b}
G5	0 (0.70)^{a}	0 (0.70)^{a}	2.20 (4.99)^{*a}	8.23 (16.51)^{b}	8.35 (16.58)^{bc}	2.38 (5.17)^{*ab}	13.73 (21.25)^{a}	15.68 (23.06)^{b}
G6	0 (0.70)^{a}	0 (0.70)^{a}	6.39 (11.08)^{ab}	6.25 (11.73)^{ab}	4.46 (9.99)^{b}	4.18 (9.67)^{ab}	17.65 (24.65)^{ab}	13.73 (21.25)^{*ab}
G7	1.96 (4.68)^{ab}	0 (0.70)^{*a}	6.39 (14.64)^{b}	6.00 (11.52)^{*ab}	6.67 (12.13)^{b}	1.96 (4.68)^{*ab}	19.61 (26.24)^{b}	9.80 (18.06)^{*a}
G8	0 (0.70)^{a}	0 (0.70)^{a}	10.17 (18.42)^{bc}	9.36 (17.57)^{b}	4.44 (9.98)^{b}	2.38 (5.17)^{*a}	17.65 (24.85)^{ab}	17.65 (24.85)^{b}
G10	0 (0.70)^{a}	0 (0.70)^{a}	10.17 (18.42)^{bc}	4.18 (9.67)^{*a}	18.25 (25.20)^{c}	0 (0.70)^{*a}	29.41 (32.78)^{c}	11.76 (19.65)^{*ab}
G11	2.38 (5.17)^{ab}	2.22 (4.99)^{ab}	12.09 (20.18)^{bc}	8.38 (16.69)^{*b}	5.55 (11.18)^{b}	2.22 (4.99)^{*ab}	33.33 (33.26)^{c}	17.65 (24.65)^{*b}
Mean	**(4.76)**	**(1.95)***	**(18.00)**	**(15.41)**	**(10.93)**	**(7.83)**	**(30.21)**	**(25.24)***
CD. P .5%	**2.67**		**3.01**		**4.44**		**2.05**	
CD. G 5%	**5.97**		**6.73**		**9.92**		**4.58**	
CD. Int. 5%	**8.44**		**NS**		**14.0**		**6.48**	

Cc., *C. cephalonia* eggs; Tc., *T. castenum* larvae; CD. P, CD Prey; CD.G, CD Generation; CD. Int., CD Interaction (PxG); Values presented are average of 51 observations (17x3 replications) each, in eggs and at start of 1st instar; Values between parentheses are arc sin transformed; *, value is significantly different for the stage in same generation (prey comparison generation wise); NS, F test not significant at 0.05 level.

cent mortality (3.92) was observed in G_1, G_5, G_8 and G_{10} and it was statistically at par with G_7. On the other hand on *T. castaneum* larvae the highest per cent mortality (13.68) was recorded for G_3 and it was statistically at par with G_1, G_2, G_5 and G_8, while the lowest per cent morality (1.96) was observed in G_7 and it was statistically at par with G_4 and G_6.

In the first instar the overall mean of all generations for mortality on either prey was significantly lower on *T. castaneum* larvae (Table 5). Considering individual generations on either prey, the first instar mortality was significantly lower on *T. castaneum* larvae in six generations (G_2, G_4, G_6, G_7, G_8 and G_{11}); while it was significantly lower on *C. cephalonica* eggs in two generations (G_1 and G_5).

In the 2nd and 3rd instars the mortality was negligible on either of the two preys. The mean of all generations revealed no significant difference between the two prey species. Some generations showed significant differences for this prey or that.

4.2.1.2.3 Pupation failure

In certain generations some larvae of the predator failed to pupate and remained for long periods (25-50 days) as larvae or prepupae, then died. This phenomenon was observed in G_3, G_4 and G_{11} on both preys and in G_3 and G_7 only in those reared on *C. cephalonica* eggs (Table 5). The overall mean of generations for each prey shows that the incidence of this phenomenon was significantly higher in larvae reared on *C. cephaloniea* eggs than in those reared on *T. castaneum* larvae. The highest per cent pupation failure (14.86) was detected in G_4 on *C. cephalonica* eggs as against 4.17 in G_2 on *T. castaneum* larvae.

4.2.1.2.4 Cocoon mortality

Statistical analysis for cocoon mortality revealed no significant difference for prey but, there was a significant difference among generations. The interaction between prey and generation was also not significant (Table 5).

Comparing the two preys in each generation, per cent cocoon mortality was significantly lower on *T. castaneum* larvae in six generations (G_1, G_3, G_4, G_7, G_{10} and G_{11}), while the mortality was significantly lower on *C. cephalonica* eggs for only one generation (G_5). In the other three generations (G_2, G_6 and G_8) the difference was not significant.

Lowest cocoon mortality (4.18%) was observed in G_{10} on *T. castaneum* larvae, which was not significantly different form G_1, G_6 and G_7, while the highest cocoon

mortality (25.09%) was observed in G_4 on *C. cephalonica* eggs and it was significantly different from other generations.

4.2.1.2.5 Malformed adult

The means for all generations on either prey were not significantly different from each other but, comparing the same generation on the two preys many generations showed significant differences for this parameter (Table 5). In five generations (G_5, G_7, G_8, G_{10} and G_{11}) per cent malformed adult was significantly lower on *T. castaneum* larvae as compared to *C. cephalonica* eggs, while in three generations (G_1, G_2 and G_4) the per cent malformation was higher on *T. castaneum* larvae.

On *C. cephalonica* eggs, highest per cent malformation (18.25) was observed in G_{10} which was not significantly different from G_5. On the other hand on *T. castaneum* larvae, the highest per cent malformed adult (9.73) was observed in G_2. There was general trend of decreasing malformed adult on *T. castaneum* larvae as generation advanced.

4.2.2 Effect on developmental period of immature stages

Results on effect of prey and continuous rearing on developmental period in different life stages of *M. boninensis* are presented in Table 6 and Fig. 3.

4.2.2.1 Total developmental period (egg to adult emergence)

Statistical analysis for total developmental period shows significant differences ($P \leq 0.05$) for prey, generation as well as interaction between prey and generation. Average developmental period in *M. boninensis* from the time egg was laid till emergence of adult was significantly shorter (20.58 days) on *C. cephalonica* eggs as against 22.65 days on *T. castaneum* larvae as shown by the overall mean of generations on either of the two preys. The average for different generations ranged between 19.43-21.63 days on *C. cephalonica* eggs and between 20.03-23.87 days on *T. castaneum* larvae.

Comparing the same generation on the two preys; on *T. castaneum* larvae the developmental period was significantly shorter than on *C. cephalonica* eggs only in one generation (G_7) which was significantly different from other generations. On the other hand in all other nine generations the period was significantly shorter on *C. cephalonuica* eggs.

Comparing different generations on the same host; the longest developmental period on *T. castaneum* larvae (23.87 days) was observed in G_3 and it was statistically at par with G_1, G_2 and G_{11}. On the other hand the shortest period on *C. cephalonica* eggs

Table 6. Generation wise developmental period (days) of *M. boninensis* reared on *C. cephalonia* eggs and *T. castenum* larvae

Generation	Egg incubation period		Larval period								Cocoon period		Total period (egg-adult)	
			1st Instar		2nd Instar		3rd Instar		Total larval					
	Cc	Tc	Cc	Tc	Cc	Tc	Cc	Tc	Cc	Tc	Cc	Tc	Cc	Tc
G1	3.13^{b}	3.07^{*b}	3.00^{*b}	3.83^{c}	2.00^{*a}	3.10^{d}	2.73^{*b}	3.70^{c}	7.73^{*b}	10.63^{d}	9.60^{c}	9.60^{b}	20.38^{*b}	23.30^{def}
G2	3.13^{b}	3.00^{*a}	3.03^{*b}	3.73^{c}	2.40^{*c}	3.20^{d}	3.37^{d}	3.77^{cd}	8.80^{*d}	10.70^{d}	9.70^{cd}	9.77^{bc}	21.63^{*d}	23.47^{def}
G3	3.17^{b}	3.17b	3.13^{*b}	3.73^{c}	2.30^{*bc}	2.97^{cd}	3.17^{*cd}	3.97^{cde}	8.60^{*d}	10.67^{d}	10.03^{d}	10.03^{c}	20.77^{*bc}	23.87^{f}
G4	3.03^{a}	2.97^{*a}	3.10^{*b}	3.43^{b}	2.20^{*b}	2.87^{c}	2.83^{*b}	4.27^{e}	8.13^{*c}	10.57^{d}	9.87^{d}	9.67^{*b}	21.03^{*c}	23.20^{de}
G5	2.97^{*a}	3.00^{a}	2.67^{*ab}	2.97^{ab}	2.33^{*bc}	3.00^{cd}	3.00^{*bc}	4.10^{e}	8.00^{*bc}	10.07^{c}	9.67^{*cd}	10.00^{c}	20.53^{*bc}	23.07^{d}
G6	3.03^{a}	3.03^{a}	3.03^{*b}	3.33^{b}	2.23^{*bc}	2.43^{b}	3.10^{*cd}	350^{bc}	8.33^{*cd}	9.27^{b}	9.90^{*d}	10.17^{c}	21.27^{*c}	22.47^{c}
G7	3.00^{a}	3.00^{a}	3.17^{*b}	2.83^{a}	2.13^{a}	2.13^{a}	3.03^{c}	3.00^{a}	8.33^{cd}	7.97^{*a}	9.73^{cd}	9.07^{*a}	21.07^{c}	20.03^{*a}
G8	3.00^{a}	3.00^{a}	2.93^{b}	3.03^{ab}	2.07^{*ab}	2.43^{b}	3.00^{*bc}	4.00^{de}	8.00^{*bc}	9.47^{bc}	8.77^{*a}	9.07^{a}	20.43^{*b}	21.53^{b}
G10	3.00^{a}	3.00^{a}	2.60^{*a}	2.77^{a}	2.27^{*bc}	2.40^{b}	2.43^{*a}	3.73^{cd}	7.30^{*a}	9.10^{b}	9.13^{*b}	9.80^{bc}	19.43^{*a}	21.90^{bc}
G11	3.00^{*a}	3.13^{b}	2.87^{*a}	3.17^{b}	2.23^{*bc}	3.20^{d}	3.43^{d}	3.37^{b}	8.53^{*d}	9.73^{c}	8.77^{*a}	10.80^{d}	20.30^{*b}	23.66^{ef}
Mean	**3.05**	**3.04**	**2.95***	**3.30**	**2.21***	**2.77**	**3.01***	**3.74**	**8.18***	**9.82**	**9.54***	**9.80**	**20.68***	**22.65**
CD. P 5%	**0.028 NS**		**0.127**		**0.085**		**0.132**		**0.173**		**0.105**		**0.259**	
CD. G 5%	**0.062**		**0.290**		**0.190**		**0.294**		**0.387**		**0.235**		**0.578**	
CD. Int. 5%	**0.088**		**0.404**		**0.268**		**0.416**		**0.548**		**0.332**		**0.818**	

Cc., *C. cephalonia* eggs; Tc., *T. castenum* larvae
CD. P, CD Prey; CD.G, CD Generation; CD. Int., CD Interaction (PxG)
Values presented are average of 51 observations (17x3 replications) each
*, value is significantly different for the stage in same generation (prey comparison generation wise)
NS, F test not significant at 0.05 level.

(19.43 days) was observed in G_{10} which was statistically different from all other generations, while the longest period (21.63 days) was recorded for G_2 which was also statistically different from all other generations (Table 6 and Fig. 3).

4.2.2.2 Egg incubation period

For egg incubation period the F test was significant for generation and for interaction between generation and prey. Average egg incubation period on either of the two preys ranged between 2.97-3.17 days. The overall means of all generations on the two hosts were statistically at par, 3.05 days for *C. cephalonica* eggs and 3.04 days for *T. castaneum* larvae. Comparing the same generation on the two preys; in three generations (G_1, G_2 and G_4) the egg incubation period was significantly shorter on *T. castaneum* larvae, while in two generations (G_5 and G_7) the period was significantly shorter on *C. cephalonica* eggs.

Comparing different generations on the same prey; on *C. cephalonica* eggs the shortest egg incubation period (2.97 days) was observed in G_5 which was statistically at par with G_4, G_6, G_7, G_8, G_{10} and G_{11}, while on *T. castaneum* larvae the shortest egg incubation period (2.97 days) was observed in G_4 and it was statistically different from G_1 and G_{11} but at par with others.

4.2.2.3 Larval developmental period

Results on larval developmental period are presented in Table 6. Statistical analysis revealed significant difference between preys, generations and interaction between prey and generation. Larval developmental period on *C. cephalonica* was significantly shorter (8.18 days) than on *T. castaneum* larvae (9.82 days).

Comparison of the same generation on the two preys showed that larval period was significantly shorter on *C. cephalonica* eggs than on *T. castaneum* larvae in nine generations. Only in G_7 the period was significantly shorter on *T. castaneum* larvae than on *C. cephalonica* eggs.

On *C. cephalonica* eggs; the shortest larval period 7.30 days was observed in G_{10} which was significantly different from all other generations, while the longest larval period (8.8 days) was observed in G_2 which was statistically at par with G_3, G_6 and G_{11}. On the other hand on *T. castaneum* larvae, longest larval period (10.7 days) was observed in G_2 which was statistically at par with G_1, G_3 and G_4, while the shortest period (7.97 days) was observed in G_7 and it was significantly different from other generations.

Statistical analysis for developmental period of different larval instars showed significant difference for prey, generation and interaction between them. The overall means of generations on either of the two preys showed significant difference for the three larval instars. The periods of the three instars were significantly shorter on *C. cephalonica* eggs (Table 6). Among generations on the same prey, also there were significant differences for each of the three larval instars.

4.2.2.4 Cocoon developmental period

The results on cocoon period (Table 6) show significant difference ($P \leq 0.05$) for prey, generation as well interaction between prey and generation. The overall mean of generations on either prey for cocoon period was significantly lower (9.45 days) on *C. cephalonica* eggs than on *T. castaneum* larvae (9.80 days). Considering each generation on the two preys, the cocoon period was significantly shorter on *C. cephalonica* eggs in five generations (G_5, G_6, G_8, G_{10} and G_{11}), while it was significantly shorter on *T. castaneum* larvae in two generations (G_4 and G_7) and in three generations (G_1, G_2 and G_3) no significant difference was detected.

Comparing different generations on the same prey; on *C. cephalonicaa* the longest cocoon period (10.03 days) was observed in G_3 which was statistically not different from G_1, G_2, G_4, G_5 and G_6, while the shortest cocoon period (8.77 days) was observed in G_8 and G_{11}, and they were statistically different from others. On the other hand, on *T. castaneum* larvae, the longest cocoon period (10.80 days) was observed in G_{11} and it was significantly different from others, while the shortest period (9.07 days) was observed in G_7 and G_8 which were significantly different from others.

Out of the 25 cocoons dissected for determination of prepupal period in G_{10}, 19 developed into pupae (shedding of the larval skin) 3-4 days (mean 3.21±0.10 days) after cocoon formation. Moreover, some larvae pupated without cocoon; they also took 3-4 days from the time they stopped feeding, becoming, short and sluggish to the time they shed the larval skin and form the pupae. So, according to these results the prepupal period was 3-4 days.

4.2.3 Effect on cocoon weight

Results on cocoon weight are presented in Table 7 and Fig. 4. Statistical analysis shows that there was statistical difference between the two preys and significant differences for the interaction between prey and generation.

The overall mean of generations was significantly higher (10.68mg) for cocoons reared on *C. cephalonica* eggs as compared to those reared on *T. castaneum* larvae

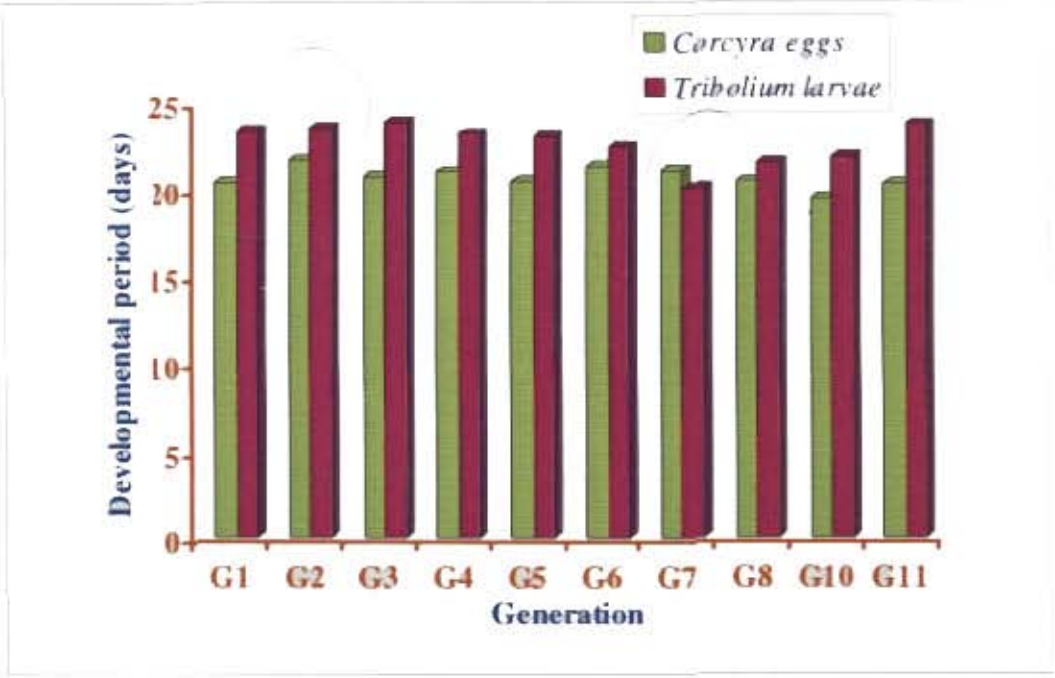


Fig. 3. Generation wise average developmental period (egg to adult) of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae

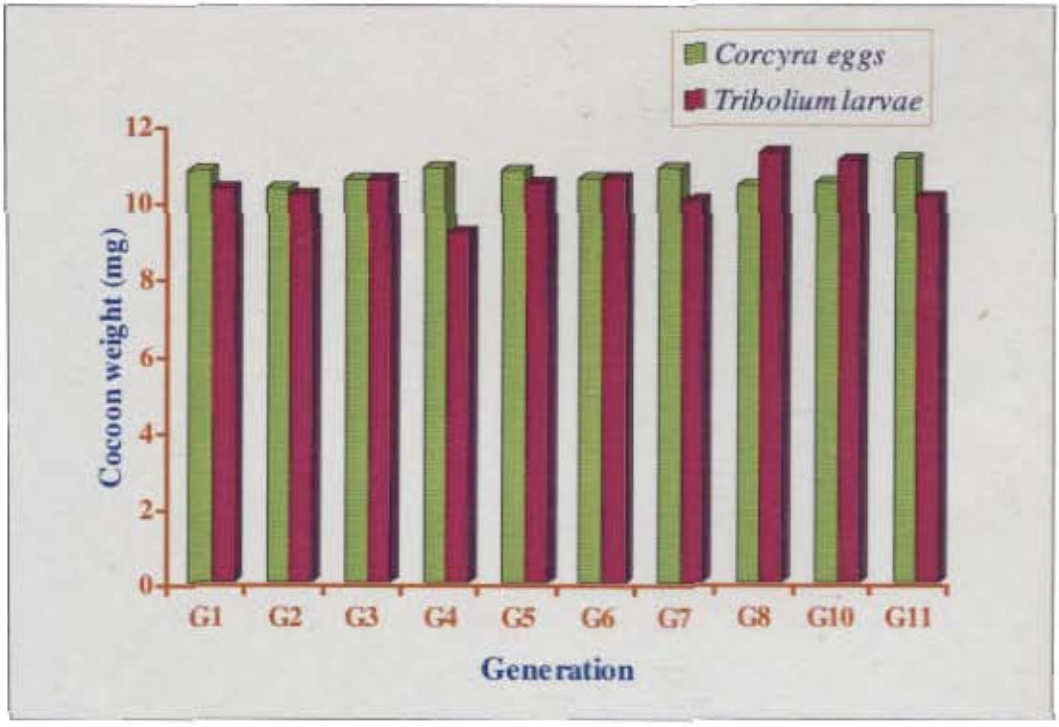
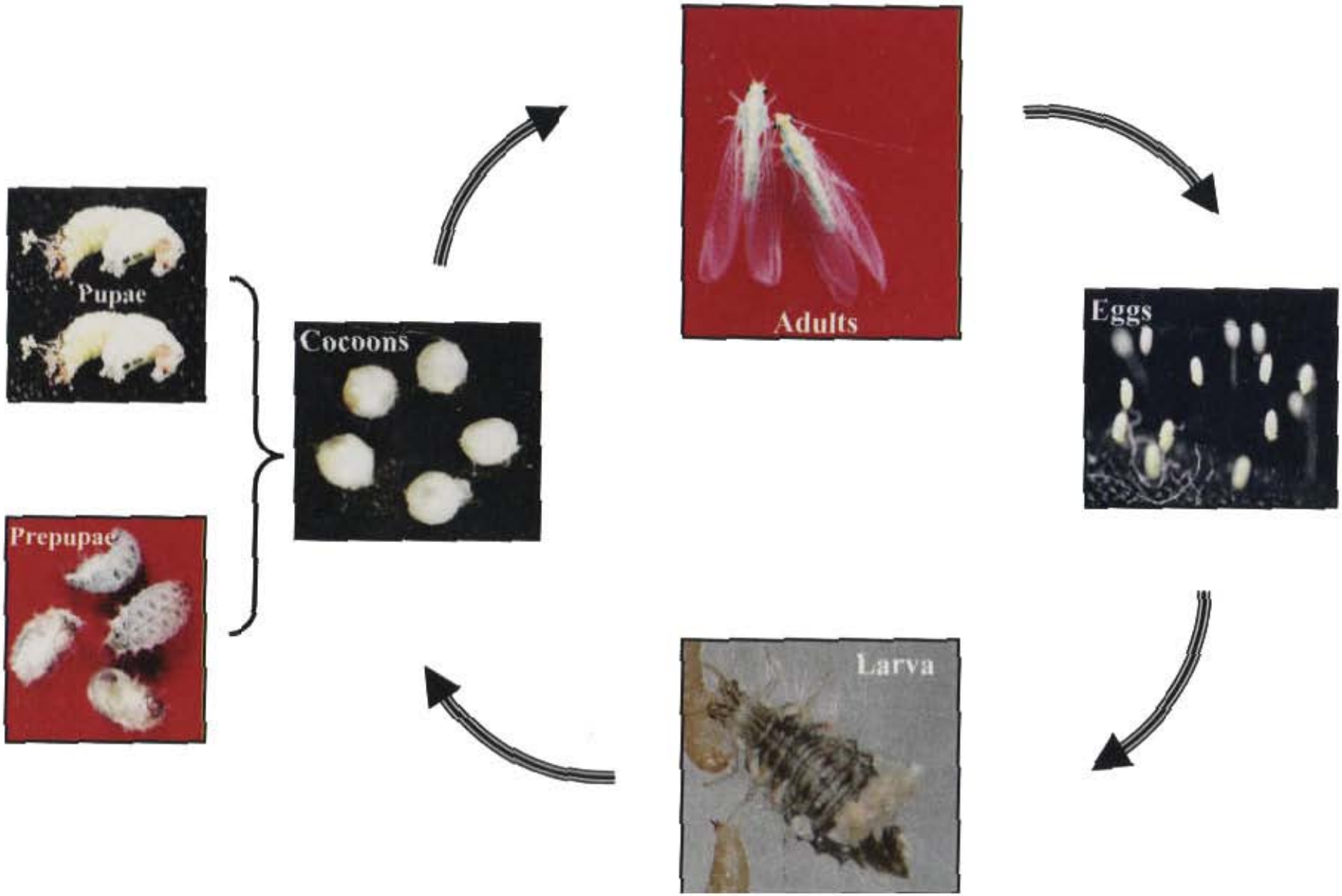


Fig. 4. Generation wise average cocoon weight of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae

Table 7. Generation wise cocoon weight and wing expanse of *M. boninensis* reared on *C. cephalonia* eggs and *T. castenum* larvae

Generation	Coccon weight (mg)			Wing expanse (mm)					
				Male			Female		
	C. cephalonica	*T. castenum*	Mean	*C. cephalonica*	*T. castenum*	Mean	*C. cephalonica*	*T. castenum*	Mean
G1	10.81*^{ab}	10.31^{b}	**10.56**	26.15*^{ab}	25.55^{b}	**25.85**	28.10*^{b}	27.45^{c}	**27.78^{c}**
G2	10.34^{b}	10.17^{b}	**10.27**	26.00^{ab}	26.15^{ab}	**26.08**	28.05*^{c}	27.50^{c}	**27.78^{c}**
G3	10.54^{ab}	10.54^{b}	**10.54**	26.05^{ab}	26.35*^{a}	**26.20**	28.10^{bc}	28.50*^{b}	**28.30^{a}**
G4	10.87*^{ab}	9.17^{c}	**10.03**	26.20*^{ab}	25.60^{ab}	**25.90**	28.30*^{b}	27.35^{c}	**27.83^{c}**
G5	10.80^{ab}	10.50^{b}	**10.65**	26.45*^{a}	25.85^{b}	**26.15**	28.45^{ab}	28.65^{ab}	**28.55^{a}**
G6	10.58^{ab}	10.61^{ab}	**10.58**	25.50^{b}	26.10*^{ab}	**25.80**	28.20^{bc}	28.35*^{b}	**28.28^{b}**
G7	10.86*^{ab}	10.00^{b}	**10.43**	26.00^{ab}	26.05^{ab}	**26.03**	28.55*^{a}	28.15^{b}	**28.35^{a}**
G8	10.38^{b}	11.26*^{a}	**10.82**	25.80^{b}	26.35*^{a}	**26.08**	28.15^{bc}	28.65*^{ab}	**28.40^{a}**
G10	10.49^{ab}	11.06*^{ab}	**10.77**	26.40^{a}	26.35^{a}	**26.58**	27.90^{c}	29.00*^{a}	**28.45^{a}**
G11	11.11*^{a}	10.09^{b}	**10.60**	26.00^{ab}	26.25*^{ab}	**26.13**	28.35^{ab}	28.80*^{ab}	**28.50^{a}**
Mean	**10.68***	**10.37**		**26.06**	**26.25**		**28.22**	**28.24**	
CD. P 5%		**0.303**			**0.207 NS**			**0.220 NS**	
CD. G 5%		**0.678 NS**			**0.464 NS**			**0.491**	
CD. Int. 5%		**0.760**			**0.655**			**0.674**	

CD. P, CD Prey; CD.G, CD Generation; CD. Int., CD Interaction (PxG)
Values presented are average of 21 pupae or 10 adults each
*, value is significantly different for the stage in same generation (prey comparison generation wise)
Means followed by the same letter in the column are not significantly different from each other
NS, F test not significant at 0.05 level.


Pupae
Prepupae
Cocoons
Adults
Eggs
Larva

(10.37mg). Comparing the means of the same generation on the two preys; in four generations (G_1, G_4, G_7 and G_{11}) the cocoon weight was significantly heavier on *C. cephalonica* eggs. On the other hand in two generations (G_8 and G_{10}) the cocoon weight was significantly heavier on *T. castaneum* larvae, and in four generations (G_2, G_3, G_5 and G_6) no significant difference was detected.

On *T. castaneum* larvae the heaviest cocoon weight (11.26mg) was observed in G_8 which was also statistically at par with G_{10}, while the lighter cocoon weight (9.17mg) was observed in G_4 which was significantly different from all others. On *C. cephalonica* eggs the heaviest cocoon weight (11.11 mg) was observed in G_{11} which was at par with G_1, G_3, G_4, G_5, G_6, G_7 and G_{10}; while the lightest cocoon weight (10.35mg) was observed in G_2 which was also statistically at par with G_1, G_3, G_4, G_5, G_6, G_8 and G_{10}.

4.2.4 Adult wing expanse

Results on adult wing expanse are presented in Table 7. Analysis of variance for male wing expanse revealed no significant difference for prey or for generation but there was significant difference for interaction ($P \leq 0.05$). In case of female wing expanse there was significant difference for generation as well as for interaction between prey and generation ($P \leq 0.05$).

For male wing expanse comparing the same generation on the two preys; the wing expanse in four generations (G_3, G_6, G_8 and G_{11}) was significantly longer on *T. castaneum* larvae, while in three generations (G_1, G_4 and G_5) it was significantly longer on *C. cephalonica* eggs. The values for wing expanse in different generations on *C. cephalonica* eggs ranged from (25.50-26.45mm) while on *T. castaneum* larvae the range was (25.55-26.35mm).

For female wing expanse; comparing the same generation on the two preys; in five generations (G_3, G_6, G_8, G_{10} and G_{11}) the wing expanse was significantly longer on *T. castaneum* larvae, while in four generations (G_1, G_2, G_4 and G_7) the wing expanse was significantly longer on *C. cephalonica* eggs.

Comparing different generations on the same prey; on *T. castaneum* larvae the longest female wing expanse (29.00mm) was recorded in G_{10} which was statistically at par with G_5, G_8 and G_{11} but, significantly different from other generations, while the shortest female wing expanse (27.35mm) was observed in G_4 which was also statistically at par with G_1 and G_2. On the other hand on *C. cephalonica* eggs, the highest value for female wing expanse (28.55mm) was observed in G_7 which was statistically not different

from G_5 and G_{11}, while the lowest value (27.91mm) was observed in G_{10} and it was statistically at par with values for G_2, G_3, G_6 and G_8.

4.2.5 Effects on adult longevity, fecundity and sex ratio

4.2.5.1 Male longevity

Results on male longevity are presented in Table 8 and Fig. 5. Analysis of variance shows significant differences for prey, generation and for interaction between prey and generation ($P \leq 0.05$). The overall mean of generations on either of the two preys indicates that male longevity was significantly higher (41.73 days) on *T. castaneum* larvae than on *C. cephalonica* eggs (37.15 days).

Considering the same generation on the two preys; in six generations (G_2, G_6, G_7, G_8, G_{10} and G_{11}) the male longevity was significantly higher on *T. castaneum* larvae, while in two generations (G_1 and G_3) it was significantly higher on *C. cephalonica* eggs.

Comparison of different generations on the same prey; on *C. cephalonica* eggs the longest male longevity was observed in G_{11} (45.75 days) which was not significantly different from G_3 and G_7, while the shortest longevity was recorded in G_2 (31.33 days) which was at par with all other generations except G_{11}. On the other hand on *T. castaneum* larvae the longest male longevity (84.67 days) was observed in G_{10} and it was significantly different from all others, while the shortest male longevity (30.33 days) was observed in G_3 and it was also at par with G_1, G_4, G_5 and G_6.

4.2.5.2 Female longevity

Results on female longevity are presented in Table 8 and Fig. 6. Analysis of variance revealed significant difference ($P \leq 0.05$) for prey, generation and interaction between prey and generation. The overall mean of generations for female longevity on *T. castaneum* larvae was significantly higher (50.56 days) than that on *C. cephalonica* eggs (44.95 days). Comparing the same generation on the two preys; in five generations (G_2, G_5, G_8, G_{10} and G_{11}) the female longevity was significantly higher on *T. castaneum* larvae, while in three generations (G_1, G_3 and G_4) the female longevity was higher on *C. cephalonica* eggs.

In different generations on the same prey; the highest female longevity on *T. castaneum* larvae (71.75 days) was observed in G_{11} which was at par with G_{10} but, significantly different from other generations, while the shortest female longevity (39.58 days) was observed in G_4 which was also at par with G_1, G_3, G_5, G_6 and G_7. On the

Table 8. **Generation wise adult longevity, fecundity and sex ratio of *M. boninensis* reared on *C. cephalonia* eggs and *T. castenum* larvae**

Gene-ration	Male longevity (days)		Female longevity (days)								Fecundity		Sex ratio (M : F)	
			Preoviposition period		Oviposition period		Postoviposition period		Total female longevity					
	Cc	Tc	Cc	Tc	Cc	Tc	Cc	Tc	Cc	Tc	Cc	Tc	Cc	Tc
G1	36.17*^{b}	32.43^{d}	5.50^{b}	4.83*^{c}	42.25*^{a}	38.75^{bc}	3.33	2.92	51.08*^{a}	46.50^{bc}	579.50^{a}	617.75^{b}	1:1.14	1:1.05
G2	31.33^{b}	45.08*^{c}	6.08^{c}	6.33^{e}	33.25^{b}	40.75*^{b}	3.25	2.33	42.58^{b}	49.42*^{b}	363.58^{bc}	491.83*^{c}	1:0.54	1:1.19
G3	43.92*^{ab}	30.33^{d}	5.58^{b}	4.67*^{c}	39.08*^{ab}	35.08^{bc}	3.25	4.42	47.83*^{ab}	43.83^{bc}	475.08^{ab}	477.67^{c}	1:1.15	1:1
G4	35.08^{b}	36.08^{d}	4.42^{a}	4.33^{b}	36.58*^{ab}	31.58^{c}	4.25	4.33	45.25*^{ab}	39.58^{c}	454.58^{b}	471.41^{c}	1:0.79	1:1.29
G5	34.08^{b}	35.92^{d}	5.33*^{b}	5.83^{d}	31.83^{b}	34.67^{bc}	5.58	4.92	41.92^{b}	45.42*^{bc}	471.83^{ab}	436.00^{c}	1:0.70	1:0.88
G6	32.58^{b}	37.42*^{d}	5.50^{b}	4.92*^{c}	34.50^{b}	36.17^{bc}	4.00	2.67	44.00^{ab}	43.75^{bc}	318.50^{c}	401.83*^{c}	1:1.05	1:1.53
G7	41.58^{ab}	47.00*^{c}	6.25^{c}	4.03*^{a}	32.75^{b}	34.83^{bc}	3.92	3.67	42.83^{b}	43.00^{bc}	362.58^{bc}	411.42^{c}	1:0.71	1:1.32
G8	36.33^{b}	47.00*^{c}	5.33^{b}	4.47*^{bc}	36.08^{ab}	40.67*^{b}	3.42	3.67	45.17^{ab}	48.38*^{b}	386.75^{bc}	459.5*^{c}	1:0.92	1:0.97
G10	34.67^{b}	84.67*^{a}	5.58^{b}	4.50*^{bc}	27.92^{b}	60.25*^{a}	5.42	4.25	38.92^{b}	69.00*^{a}	267.83^{c}	876.75*^{a}	1:1.06	1:1
G11	45.75^{a}	64.33*^{b}	5.33^{b}	4.58*^{bc}	36.00^{ab}	62.08*^{a}	8.58	5.08	49.92^{ab}	71.75*^{a}	385.33^{bc}	797.33*^{a}	1:1.54	1:0.86
Mean	**37.15**	**41.73***	**5.49**	**4.93***	**35.03**	**41.48***	**4.5**	**3.83**	**44.95**	**50.06***	**406.56**	**544.15***	**1:0.90**	**1:1.08**
CD. P 5%	**3.507**		**0.210**		**3.265**		**NS**		**3.467**		**49.760**			
CD. G 5%	**7.841**		**0.270**		**7.300**		**NS**		**7.751**		**111.267**			
CD. Int. 5%	**11.089**		**0.381 NS**		**10.323**		**NS**		**10.962**		**157.355**			

Cc., *C. cephalonia* eggs; Tc., *T. castenum* larvae; CD. P, CD prey; CD. G, CD Generation; CD.Int., CD Interaction

*, value is significantly different for the stage in same generation (prey comparison, generation wise)

Means followed by the same letter in the column are not significantly different from each other

Values presented are mean of 12 observations (pairs of adult) each; NS, F test not significant at 0.05 level.

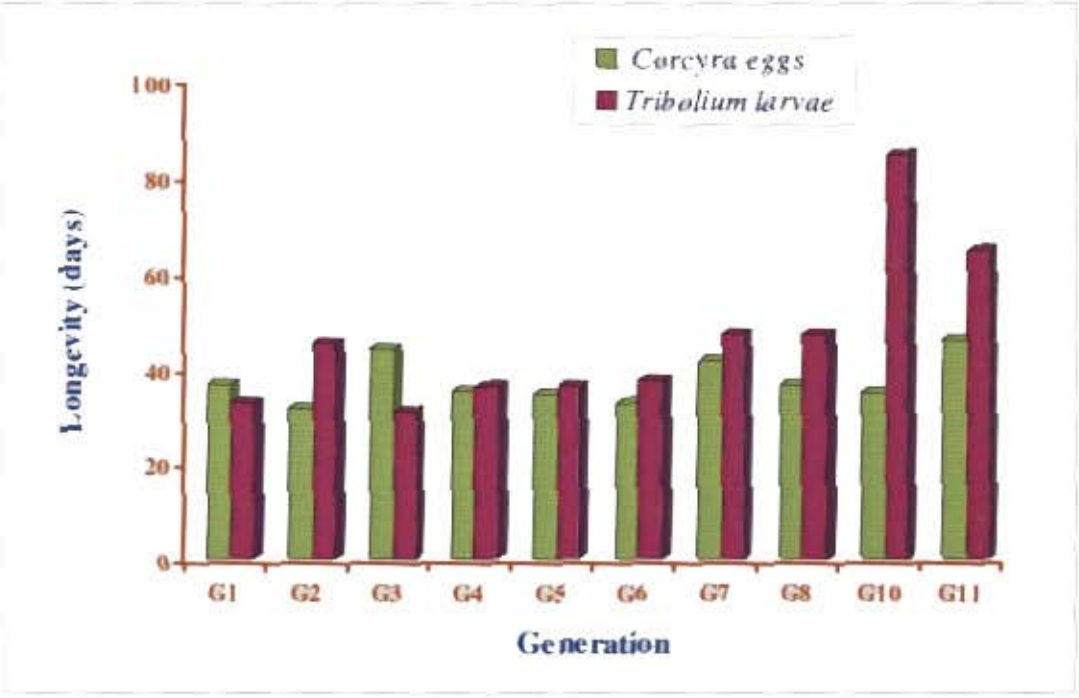


Fig. 5. Generation wise average male longevity of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae

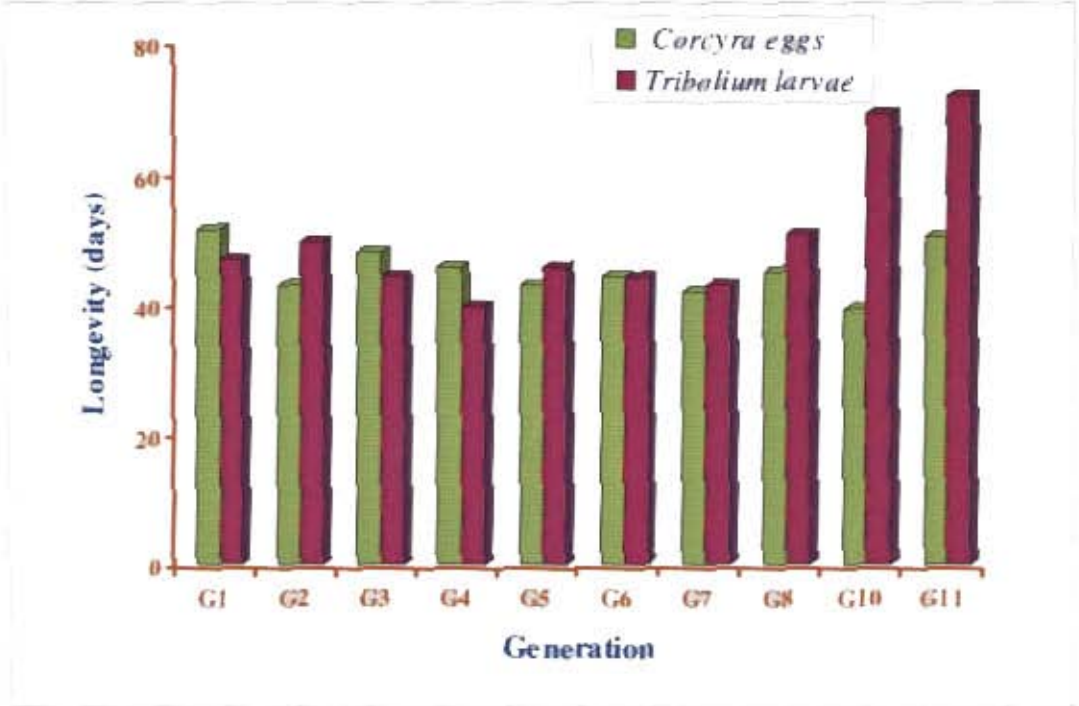


Fig. 6. Generation wise average female longevity of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae

other hand on *C. cephalonica* eggs the highest female longevity (51.08 days) was observed in G_1 which was also at par with G_3, G_4, G_6, G_8 and G_{11}, while the shortest female longevity (38.92 days) was observed in G_{10} and it was at par with other generations except G_1.

4.2.5.2.1 Pre-oviposition period

The overall mean of generations on either of the two preys shows that preoviposition period was significantly shorter (4.93 days) on *T. castaneum* larvae than on *C. cephalonica* eggs (5.49 days).

Considering the same generation on the two preys; the preoviposition period on *T. castaneum* larvae was significantly shorter than on *C. cephalonica* eggs in seven generations (G_1, G_3, G_6, G_7, G_8, G_{10} and G_{11}), while it was significantly shorter on *C. cephalonica* eggs in only one generation (G_5).

4.2.5.2.2 Oviposition period

Results on oviposition period are presented in Table 8. Analysis of variance showed that F test for oviposition period was significant for prey, generation and interaction between them ($P \leq 0.05$). The overall mean of generations on either of the two preys revealed that oviposition period was significantly longer (41.48 days) on *T. castaneum* larvae than on *C. cephalonica* eggs (35.03 days). Taking the same generation on the two preys, the oviposition period was significantly longer on *T. castaneum* larvae than on *C. cephalonica* eggs in four generations (G_2, G_8, G_{10} and G_{11}), while it was significantly longer on *C. cephalonica* eggs in three generations (G_1, G_3 and G_4).

Comparing different generations on the same prey, the longest oviposition period on *T. castaneum* larvae (62.08 days) was recorded in G_{11} which was statistically at par with G_{10} but significantly different from other generations, while the shortest oviposition period (31.58 days) was recorded in G_4 which was at par with G_1, G_3, G_5, G_6 and G_7. On the other hand on *C. cephalonica* eggs the longest oviposition period (42.25 days) was observed in G_1 which was significantly different from all other generations, while the shortest oviposition period (27.92 days) was observed in G_{10} which was not significantly different from all other generations except G_1 (Table 8 and Fig. 6).

4.2.5.2.3 Post-oviposition period

Statistical analysis showed no significant difference between preys or among generations for postoviposition period. The mean values for postoviposition period in different generations on *C. cephalonica* eggs ranged from (3.25 - 8.05) days, while on

T. castaneum larvae it varied from (2.92 - 5.08) days.

4.2.5.3 Female fecundity

Results on fecundity are presented in Table 8 and Fig. 7. Statistical analysis revealed significant differences ($P \leq 0.05$) for prey, generation and interaction between them. The overall mean of generations on either of the two preys shows that fecundity on *T. castaneum* larvae was significantly higher (544.15 eggs/female) than on *C. cephalonica* eggs (406.56 eggs/female). Comparing the same generation on the two preys; fecundity on *T. castaneum* larvae was higher in all generations except G_5 and the difference was significant in five generations (G_2, G_6, G_8, G_{10} and G_{11}).

Comparing fecundity on the same prey in different generations; the highest fecundity performance on *C. cephalonica* eggs (579.50 eggs/female) was expressed by G_1 which was statistically at par with G_3 and G_5, while the lowest fecundity (267.83 eggs/females) was expressed by G_{10} and it was statistically at par with G_2, G_6, G_7 and G_8. On the other hand the highest fecundity performance on *T. castaneum* larvae (876.75 eggs/female) was observed in G_{10} which was statistically at par with G_{11}, while the lowest fecundity (401.83 eggs/female) was observed in G_6 and it was statistically at par with (G_2, G_3, G_4, G_5, G_7 and G_8).

Fig. 8 shows the average oviposition trend per female per week throughout the oviposition period of adult on the two preys in ten generations. The trend of egg laying shows that in all generations except G_1 on both preys and G_3 on *C. cephalonica* eggs, the curve rise sharply reaching the peak of oviposition during the 2nd week of adult life then it sloped down gradually till the end of oviposition period. In G_1 on both preys and G_3 on *C. cephalonica* eggs the curves rise gradually reached the peak during the 3rd or 4th week then sloped down gradually.

4.2.5.4 Egg hatchability as adult advanced in age

Fig. 9 shows per cent egg hatchability as adult advanced in age, taken for G_{10} on the two prey species. The hatchability per cent was higher and more consistent on *T. castaneum* larvae than on *C. cephalonica* eggs.

4.2.5.5 Sex differentiation and sex ratio

Observations on the two groups of newly emerged adults separated on bases of morphological differences and kept individually for sex differentiation, revealed that all individuals of group (A) started laying eggs during the first week. No any individual from group (B) laid any egg. Moreover, the abdomen of the individuals in group (A)

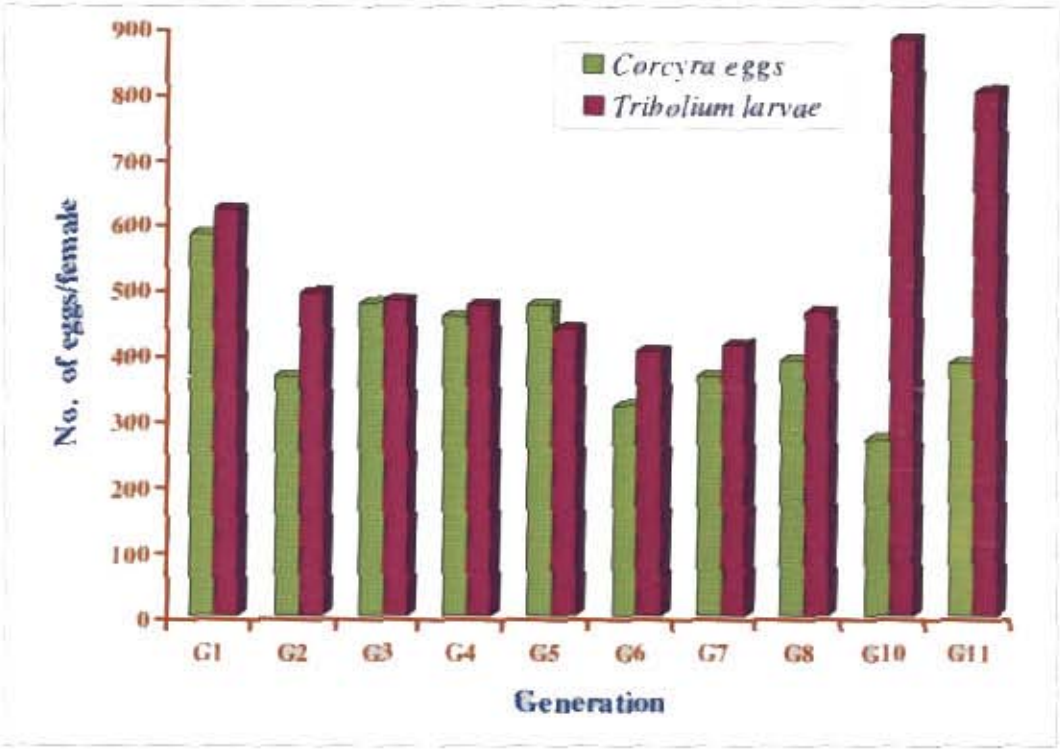


Fig. 7. Generation wise fecundity of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae

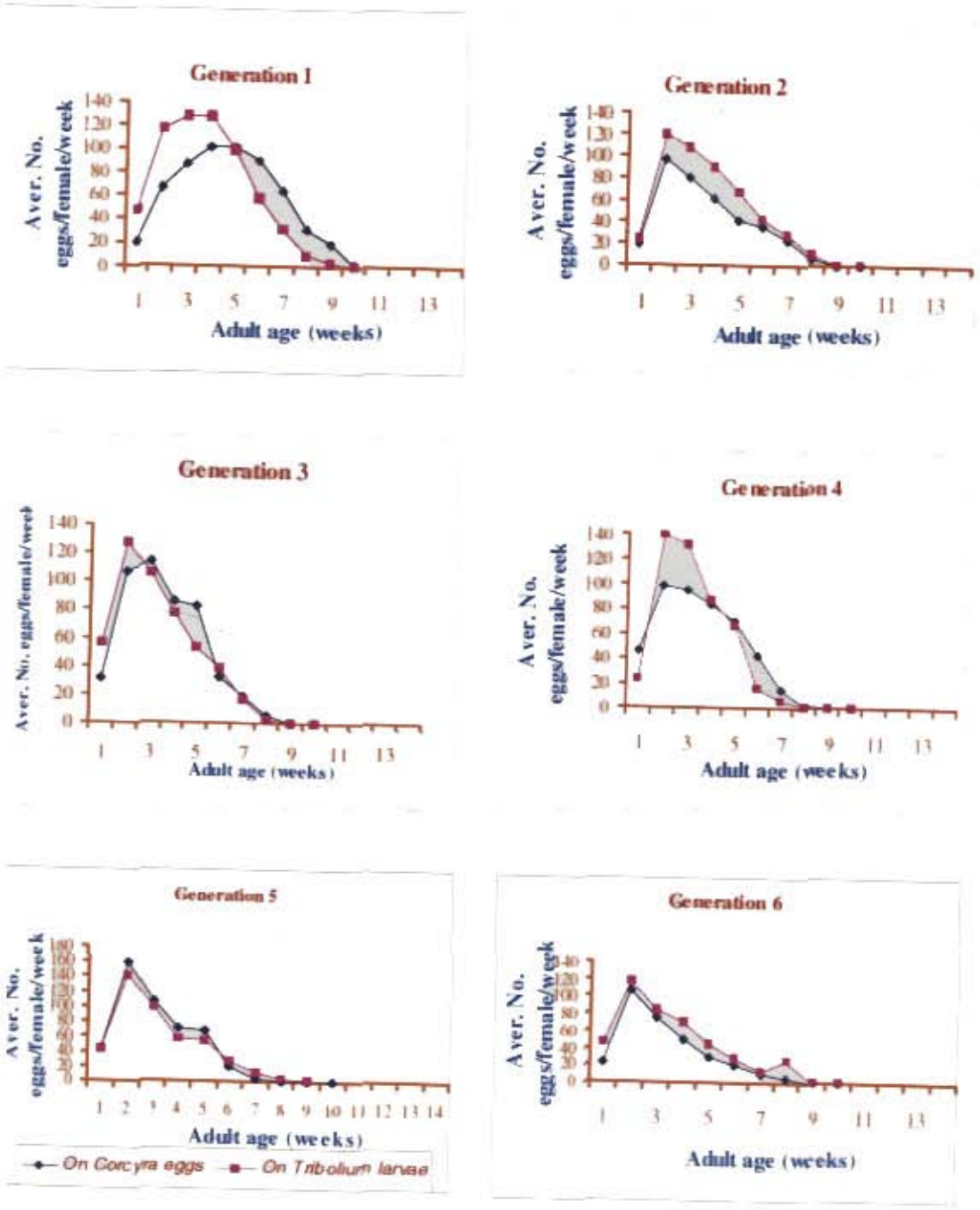


Fig. 8. Weekly ovipositional trend of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae

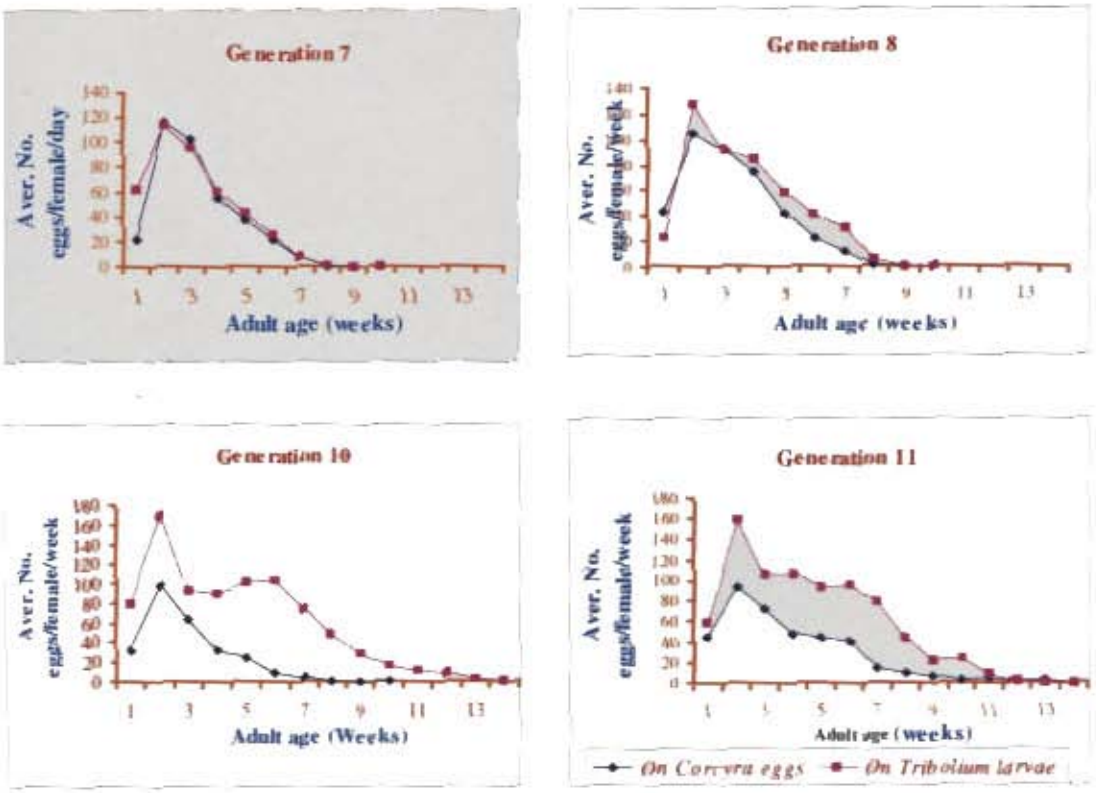


Fig. 8. Continued.....

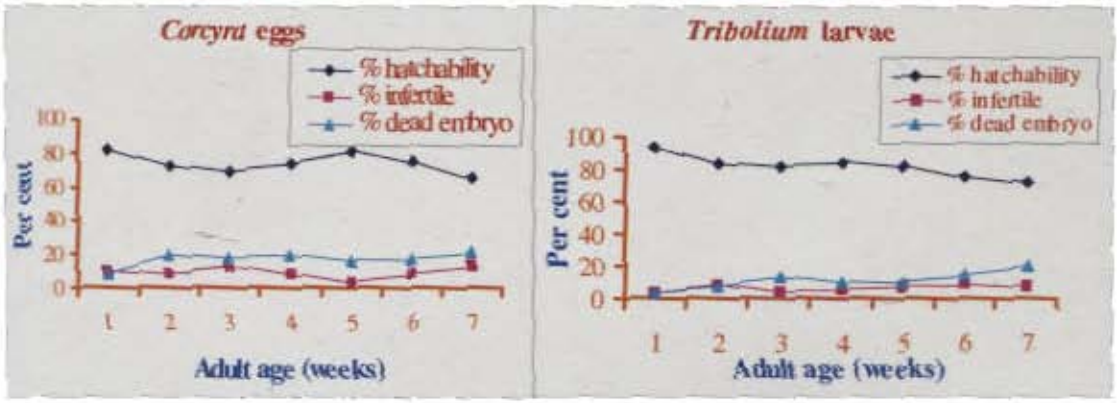


Fig. 9. Per cent egg hatchability of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae, as adult advanced in age

increased in size compared to that of individuals from group (B). All eggs laid were bright green in colour, small in size, misshaped and exclusively stalkless.

Depending on these observations we concluded that all individuals in group (A) were females and consequently the characters used for differentiation were valid and can be used to distinguish between male and female. Plate 3 shows the features of the tip of abdomen in male and female imago as fallows:

Female

- The posterior end of the abdomen blunt (truncated).
- Presence of ventral longitudinal slit on the last abdominal segment.
- Last two abdominal sternites (8^{th} and 9^{th}) separated (intersegmental line prominent).

Male

- The posterior end of abdomen sharply tapering and pointing backword (clear from ventral side).
- No ventral longitudinal slit on the last abdominal segment.
- Sternites of the last two abdominal segments (8^{th} and 9^{th}) are united (intersegmental line not prominent).

These characters were used to sex newly emerged adults on the first day of emergence in different generations.

Sex ratio for adults produced on either of the two preys in ten generations was shown in Table 8. The overall sex ratio for all generations was 1:0.90 (M:F) on *C. cephalonica* eggs and 1:1.08 (M:F) on *T. castaneum* larvae. The range of sex ratio in different generations reared on *C. cephalonica* eggs was (1:0.54 - 1:1.54) (M:F), while on *T. castaneum* larvae it was (1:0.86 – 1:1.53) (M:F).

4.3 Construction and Analysis of Life Tables

Cohort life and fecundity tables of *M. boninensis* reared continuously on *C. cephalonica* eggs and *T. castaneum* larvae were constructed on generation eight (G_8) on the two preys. Results on the statistics of these studies are presented in the following paragraphs.

In female *posterior end* of abdomen is blunt, while in male it is sharply tapering and *pointing* backward.
Presence of ventral longitudinal slit on ventral side of last abdominal *segment in female*, while in male no slit is present

Plate 3. Sex differentiation in *M. boninensis*

Table 9. Mortality of immature stages (numbers, out of 100 eggs) of *M. boninensis* reared *on C. cephalonica* eggs and *T. castaneum* larvae

Stage	Prey	
	C. cephalonica eggs	*T. castaneum* larvae
Egg	14	8
Larval	5	5
Cocoon	9	8
Malformed adult	1	2
Total immature mortality	**29**	**23**

Table 10. Mean developmental period (days±SE) of immature stages of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae

Stage	Prey	
	C. cephalonica eggs	*T. castaneum* larvae
Egg	3.0±0.00	3.0±0.00
Larval	8.0±0.09	9.5±0.14
Cocoon	9.0±0.16	9.0±0.11
Pre-oviposition period	5.3±0.28	4.5±0.18
Total life cycle (egg to egg)	**25.3**	**26**

4.3.1 Mortality of immature stages

Results on stage specific mortality of immature stages of *M. boninensis* on *C. cephalonica* eggs and *T. castaneum* larvae are presented in Table 9. Out of initial 100 eggs taken from each of the two populations, the total immature mortality was 29 individuals on *C. cephalonica* eggs and 23 individuals on *T. castaneum* larvae. This included egg, larval and cocoon mortality in addition to malformed adults. Total number of adults obtained in the two stocks was 71 (34 females and 37 males) on *C. cephalonica* eggs and 77 (38 females and 39 males) on *T. castaneum* larvae. Further details on these adults are presented in the age-specific life and fecundity tables (Tables 11 and 12).

4.3.2 Developmental period of immature stages

Average developmental period of each stage on the two preys is presented in Table 10. The average developmental period (egg to egg) was 25.3 days on *C. cephalonica* eggs, while it was 26 days on *T. castaneum* larvae.

4.3.3 Age-specific life tables

Results on the age-specific cohort life tables of *M. boninensis* on the two preys are presented in Table 11. Provided that total life span of the predator was long (more than 80 days), the age interval was chosen as seven days. Details on survivorship and mortality were computed for each age interval on the two preys, and life expectancy was estimated for each age interval (Table 11 and Fig.10, 11).

The rate of mortality (q_x) indicated that during age interval (0-7 days) the mortality was higher (0.17) on *C. cephalonica* eggs than on *T. castaneum* larvae (0.11), while during age interval (70-77 days) the (q_x) was higher (0.833) on *T. castaneum* larvae than on *C. cephalonica* eggs (0.625). The life expectancy column (e_x) Table 11 and Fig. 11 show the expectation of life in units of age interval (7 days) and days, respectively, i.e. life expectancy for the 1st age interval (0-7 days) was 6.51 (45.57 days) on *C. cephalonica* eggs and 6.99 (48.93 days) on *T. castaneum* larvae, while during age interval (63-70 days) it was 1.00 (7.0 days) and 1.012 (7.08 days) on the two preys, respectively.

Survivorship curves Fig. 10 shows that the curves on the two preys were a more or less type I curve which implies relatively low rate of mortality during immature stages and a relatively high rate during the late adult age. The curve is slightly higher for the stock reared on *T. castaneum* larvae except during the age interval (70-77 days) which is slightly higher for those reared on *C. cephalonica* eggs.

Table 11. Life tables of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae

Age interval (days)	Numbers surviving at start of age, x		Number dying during age interval, x	Rate of mortality during age interval, x	No. alive on average during age interval (l_x to l_{x+1})	Individuals X time units	Mean expectation of further life $x : T_x/l_x$
(x)	(l_x)		(d_x)	(q_x)	(L_x)	(T_x)	(e_x)
***C. cephalonica* eggs**							
0-7	100	Immature	17	0.170	91.5	651.0	6.510
7-14	83		2	0.024	82	559.5	6.741
14-21	81		10	0.123	76	477.5	5.895
21-28	71	Adults	5	0.070	68.5	401.5	5.654
28-35	66		0	0.000	66	333.0	5.045
35-42	66		1	0.015	65.5	267.0	4.045
42-49	65		6	0.092	62	201.5	3.100
49-56	59		9	0.153	54.5	139.5	2.364
56-63	50		10	0.200	45	85.0	1.700
63-70	40		25	0.625	27.5	40.0	1.000
70-77	15		10	0.667	10	12.5	0.833
77-84	5		5	1.000	2.5	2.5	0.500
84-91	0		-	-	-	0	0.0
***T. castaneum* larvae**							
0-7	100	Immature	11	0.110	94.5	699	6.990
7-14	89		2	0.022	88	604.5	6.792
14-21	87		10	0.115	82	516.5	5.937
21-28	77	Adults	2	0.026	76	434.5	5.643
28-35	75		2	0.027	74	358.5	4.780
35-42	73		3	0.041	71.5	284.5	3.897
42-49	70		7	0.100	66.5	213	3.043
49-56	63		10	0.159	58	146.5	2.325
56-63	53		12	0.226	47	88.5	1.670
63-70	41		23	0.561	29.5	41.5	1.012
70-77	18		15	0.833	10.5	12	0.667
77-84	3		3	1.0	1.5	1.5	0.5
84-91	0		0	-	0	0	0.0

Table 12. Fecundity tables of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae

Age interval (days) (x)	Pivotal age (days) (x)	Survivals at start of age, x (l_x)		No. female off-spring per female aged x per week (m_x)	$l_x m_x$	$xl_x m_x$
		Numbers	Prob-ability			
0-7	3.5	Immature				
7-14	10.5					
14-21	17.5					
21-28	24.5	34	0.68	22.80	15.5040	379.8480
28-35	31.5	32	0.64	63.08	40.3712	1271.6928
35-42	38.5	32	0.64	51.00	32.6400	1256.6400
42-49	45.5	32	0.64	35.75	22.8800	1041.0400
49-56	52.5	31	0.62	24.55	15.2210	799.1025
56-63	59.5	29	0.58	13.46	7.8068	464.5046
63-70	66.5	25	0.50	6.58	3.2900	218.7850
70-77	73.5	11	0.22	5.7	1.254	92.1690
77-84	80.5	3	0.06	2.5	0.150	12.0750
84-91	87.5	0	0.00	0	0.00	0.00
		Σ		**225.42**	**139.117**	**5535.8569**
		***T. castaneum* larvae**				
0-7	3.5	Immature				
7-14	10.5					
14-21	17.5					
21-28	24.5	38	0.76	18.01	13.6876	335.3462
28-35	31.5	37	0.74	65.93	48.7882	1536.8283
35-42	38.5	36	0.72	51.88	37.3536	1438.1136
42-49	45.5	34	0.68	43.41	29.5188	1343.1054
49-56	52.5	31	0.62	33.82	20.9684	1100.8410
56-63	59.5	27	0.54	24.31	12.6412	752.1514
63-70	66.5	24	0.48	14.88	6.5472	435.3888
70-77	73.5	10	0.20	8.72	1.744	128.1840
77-84	80.5	2	0.04	4.58	0.1832	14.7476
84-91	87.5	0	0	0.00	0.00	0.00
		Σ		**265.54**	**171.4322**	**7084.7063**

Table 13. Life tables' statistics of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae.

Serial	Life/fecundity table statistic	Formula	Prey	
			C. cephalonica eggs	*T. castaneum* larvae
1	Gross reproductive rate, **GRR** (females/female/ generation)	$= \Sigma\, m_x$	225.42	265.54
2	Net reproductive rate, R_0 (females/female /generation)	$= \Sigma\, l_x m_x$	139.117	171.43
3	Approximate generation time, T_c (days)	$= \Sigma\, x l_x m_x / \Sigma\, l_x m_x$	39.793	41.33
4	Capacity for increase, r_c (females/female /day)	$= \log_e R_0 / T_c$	0.12402471	0.124475061
5	Intrinsic rate of natural increase, r_m (females/ female/day)	Substituted in equation $\Sigma e^{-rmx} l_x m_x = 1$	0.1458789	0.1478956
6	Finite rate of increase, λ (females/female/day)	$= e^{rm}$	1.157056176	1.15939185
7	Mean generation time, T (days)	$= \log_e R_0 / r_m$	33.83	34.78
8	Doubling time, **DT** (days)	$= \log_e 2 / r_m$	4.75	4.69

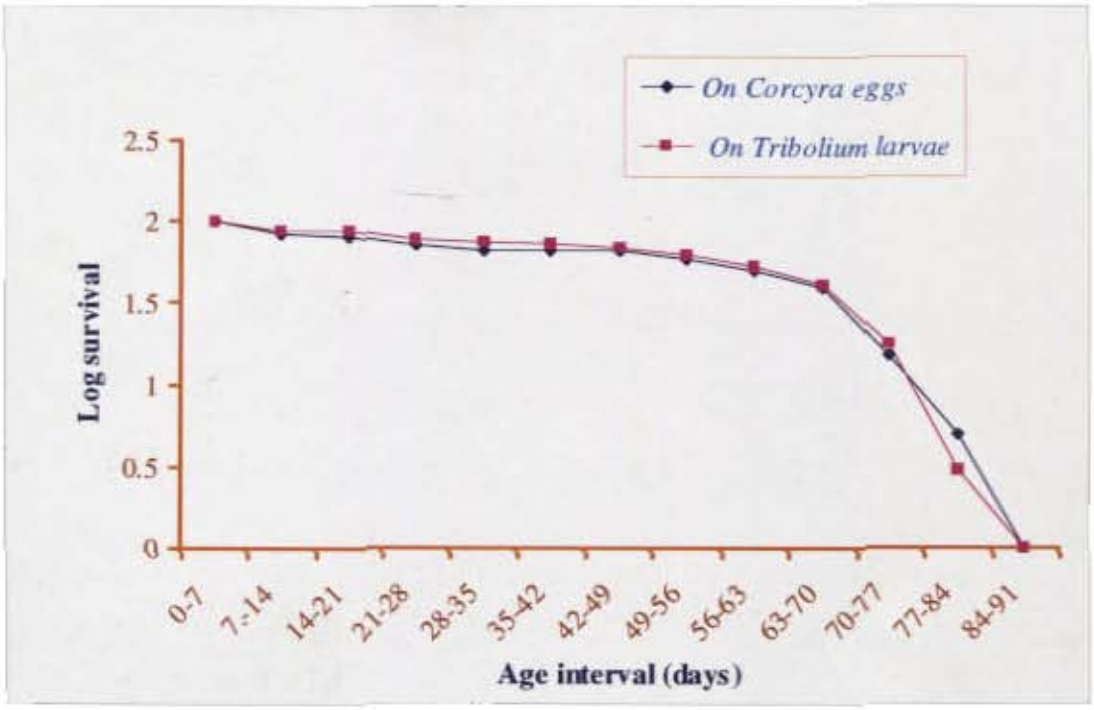


Fig. 10. Survivorship curve of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae

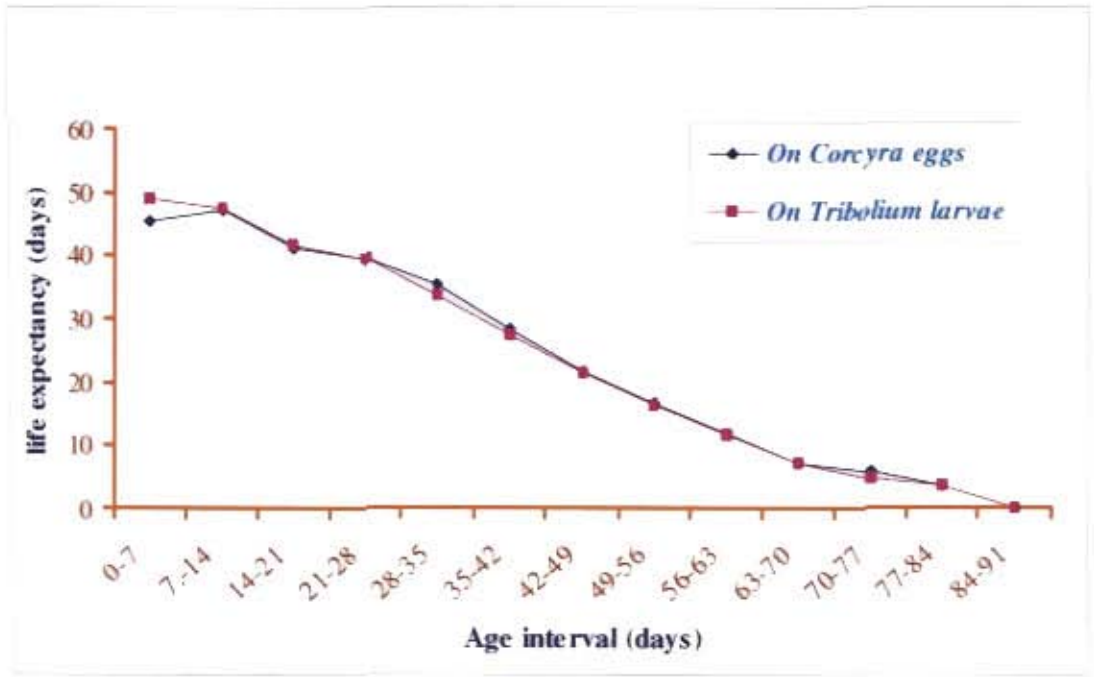


Fig. 11. Life expectancy of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae

4.3.4 Age-specific fecundity tables

Results on age-specific fecundity tables are given in Table 12. The predator stock reared on either of the two prey species started egg laying during the 4th age interval (21-28 days) which corresponded to the first week of adult emergence. The maximum female progeny (m_x)(sex ratio considered 1:1) per age interval was produced during the 5th age interval (28-35 days). The maximum female progeny was 63.08 and 65.93 female eggs/female/age interval on *C. cephalonica* eggs and *T. castaneum* larvae, respectively. Last surviving females from both stocks died during the age interval (77-84 days).

Table 13 shows the comparison of life table statistics of the predator on the two preys. The gross reproductive rate (GRR) was 225.42 females/female/generation on *C. cephalonica* eggs, while it was 265.54 females/female/generation on *T. castaneum* larvae. The net reproductive rate (R_0) was 139.12 females/female/generation on *C. cephalonica* eggs, while it was 171.43 females/female/generation on *T. castaneum* larvae. Mean generation time (T) was 33.83 and 34.78 days on *C. cephalonica* eggs and *T. castaneum* larvae, respectively, while the intrinsic rate of natural increase (r_m) was 0.1458789 and 0.1478956 females/female/day on the tow preys, respectively.

4.4 Standardization of the Prey, *T. castaneum*

4.4.1 Effect of adult density on production of larvae

Larvae of *T. castaneum* became full grown after 18-19 days from the date of releasing the adults in the flour. Full-grown larvae (Plate 4) were found more suitable for the predator.

Results on standardization of adult density per 100g of wheat flour are presented in Table 14 and Fig.12, 13. For different adult densities maximum number of larvae produced was 1554.33 for the density of adults (200/100g) wheat flour, which was not significantly different from numbers produced by 140 adults (1545) or 260 adults (1496) but, significantly higher than all other adult densities.

Maximum total biomass (3.81g) was produced by adult density of 140 adults which was also at par with 200 adults but, significantly different from all other lower or higher densities of adult.

Densities of adult higher than 140/100g reduced the larval weight and size. The highest weight per larva was produced by density of 20 adults/100g flour and it was statistically at par with densities (10, 60, 100 and 140 adults) but, other higher densities of adults produce significantly low weight per larva, and the weight of larva decreased

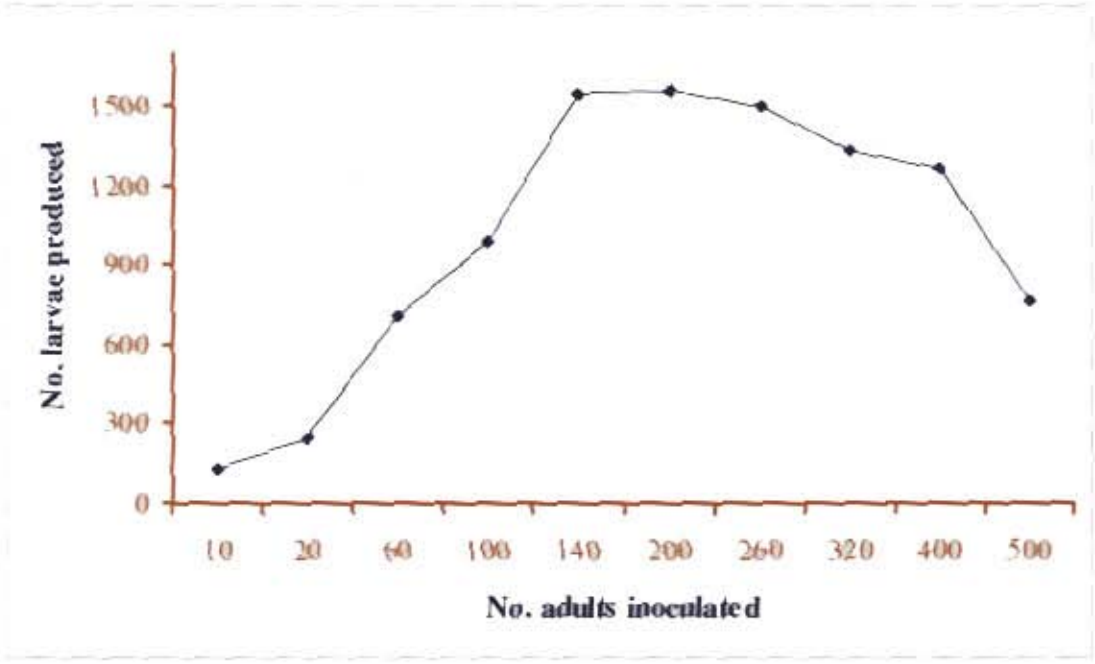


Fig. 12. Numbers of *T. castaneum* larvae produced for different levels of adults released per 100 g wheat flour

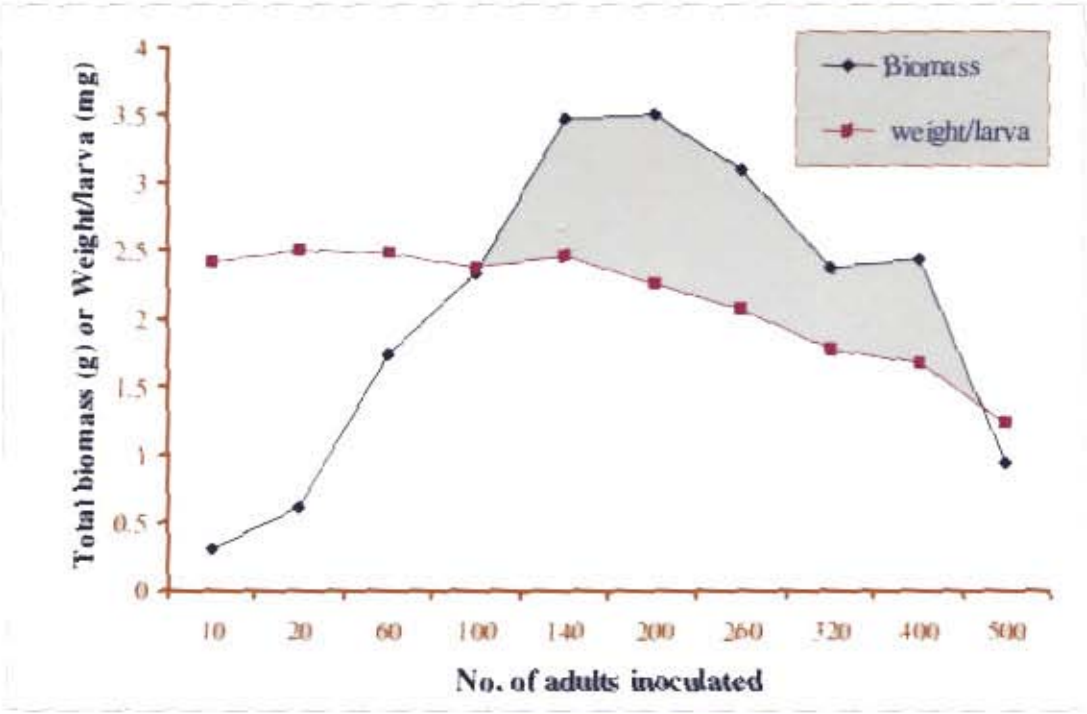
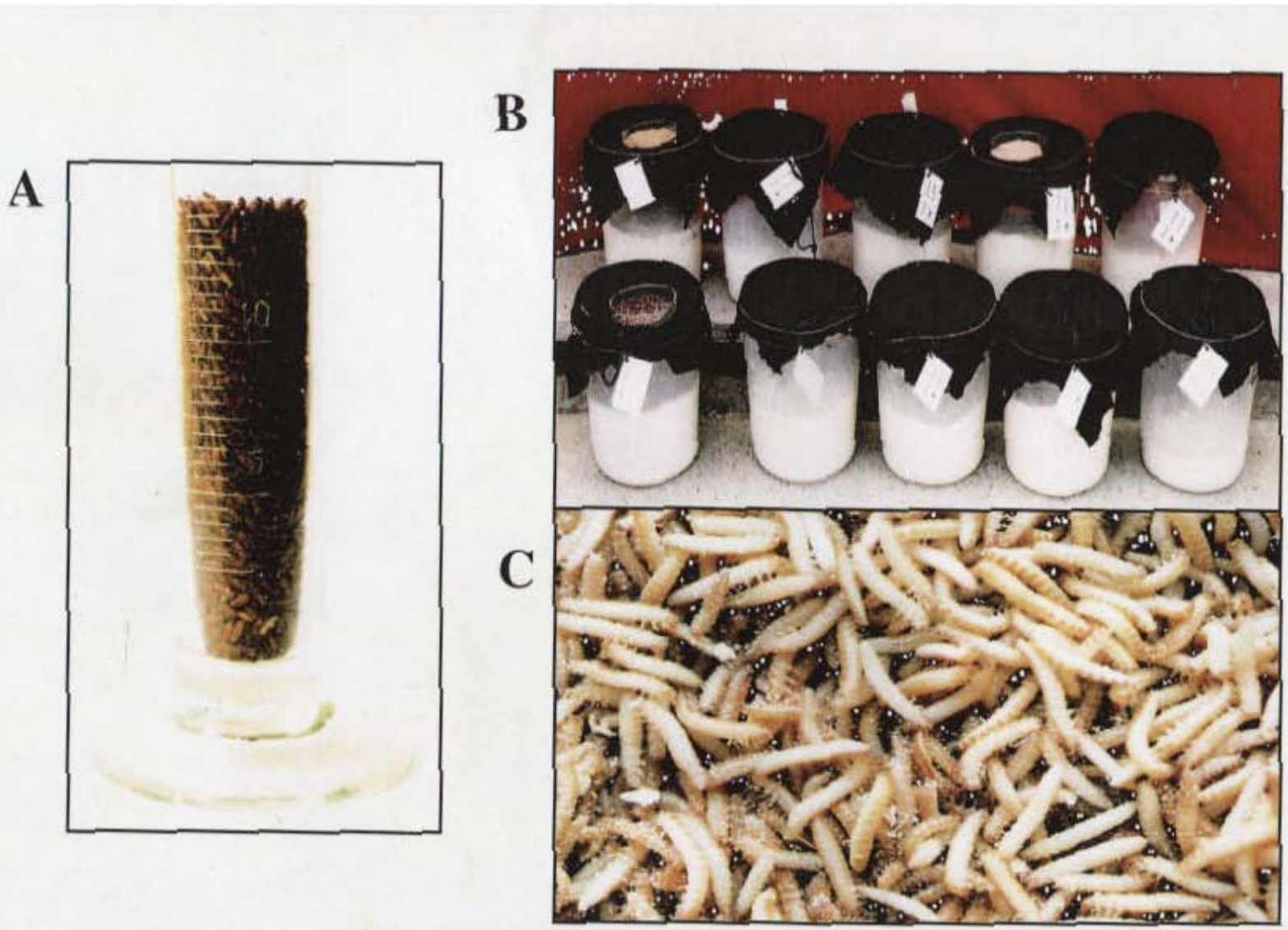


Fig. 13. Total biomass and weight/larva of *T. castaneum* larvae produced for different levels of adults inoculated per 100 g wheat flour



A. Quantification of adults by volume, B. Rearing jars, C. Full grown larvae

Plate 4. Rearing of *T. castaneum* for production of larvae

as we go for higher density. From these comparisons density of 140 adults per 100g of wheat flour was identified as optimal to produce good number of larvae with maximum biomass and reasonable weight of individual larva. According to that average, for 1kg of wheat flour we need 1400 adults to produce, 15,450 full grown larvae which produce biomass of 30.8g.

4.4.2 Quantification of *T. castaneum* adults

Samples taken to quantify the adult beetle by volume or weight (Table 15) revealed that the average number of adult beetle in 1 ml volume equal 246±3.96 and the number of adult beetles in 100mg weight equal 53.47±0.46 = (534.7 beetles/g). According to this, to release the optimum number of adult beetle (1400) into 1kg of wheat flour we need 5.7ml or 2.64g of adults.

4.4.3 Standardization of *T. castaneum* larvae for *M. boninensis*

4.4.3.1 Standardization of age

Results on the effects of age of *T. castaneum* larvae on survival, developmental period of larval-cocoon stage and weight of cocoon of *M. boninensis* are presented in Table 16.

Survival during larval cocoon period of the predator was significantly higher (96.30%) on full-grown larvae as against 77.78% on younger larvae. Larval-cocoon developmental period was significantly shorter on full-grown larvae (18.87 days) as compared to 19.29 days on younger larvae. The difference in cocoon weight was not significant although its value was higher (10.73mg) on full-grown larvae as compared to10.26mg on younger *T. castaneum* larvae. Therefore, full-grown *T. castaneum* larvae were considered more suitable for survival and development of *M. boninensis* than younger larvae.

4.4.3.2 Standardization of numbers

Results on the effect of offering different numbers of *T. castaneum* larvae for *M. boninensis* are presented in Table 17. Statistical analysis revealed significant difference ($P \leq 0.05$) for per cent larval-cocoon survival and for cocoon weight but no significant difference was detected for larval-cocoon developmental period. The treatments tested were: Regime-1 (1,1,1,....) larva per day, Regime-2 (1,1,1,2,2,...), Regime-3 (1,1,1,2,2,2,3,3,...), Regime-4 (1,1,1,2,2,2,4,4,...), Regime-5 (1,1,1,2,2,2,5,5,...) and Regime-6 (2,2,2,4,6,6,...).

Table 15. Quantification of *T. castaneum* adult by volume and weight

Sample	No. beetles/ml (Average± SE)	No. beetles/100 mg (average±SE)
1	244.42±2.64	54.3±0.47
2	242.57±2.37	53.4±0.72
3	247.43±3.08	52.7±0.68
Average ± SEm	**246.64±3.96**	**53.47±0.46**

Each value is an average of 7 observations
Samples taken one month apart.

Table 16. Survival (%), developmental period (neonate larva- adult, days), and cocoon weight of *M. boninensis* reard on full grown and younger *T. castaneum* larvae

Treatment	Survival (%)	Developmental period (days)	Cocoon weight (mg)
Full-grown	96.30 (83.56)[a]	18.57[a]	10.73
Younger	77.78 (62..42)[b]	19.29[b]	10.26
SEm±	**5.61**	**0.23**	**0.23**
CD at 5%	**16.29**	**0.68**	**NS**
CD at 1%	**22.00**	**0.91**	**NS**

Means compared using CD at 0.05
Means followed by the same letter in the column are not significantly different from each other
Values between parentheses are arc sin transformed
Values are average of 3 replications each
NS, F test is not significant.

Table 17. Survival (%), developmental period (neonate larva- adult, days), and cocoon weight of *M. boninensis* offered different numbers of *T. castaneum* larvae per day

Treatment	Average No*. *Tribolium* larvae offered/larva	Survival (%)	Developmental period (neonate-adult) (days)	Cocoon weight (mg)
Regime-1 (1,1,1.....)	9.30[f]	60.00 (50.79)[b]	19.19	6.58[c]
Regime-2 (1,1,1,2,2.....)	15.00[e]	100.00 (90.00)[a]	18.80	8.96[b]
Regime-3 (1,1,1,2,2,2,3,3...)	20.05[d]	93.33 (81.16)[a]	19.45	9.21[b]
Regime-4 (1,1,1,2,2,2,4,4...)	23.13[c]	93.33 (81.16)[a]	19.60	10.33[a]
Regime-5 (1,1,1,2,2,2,5,5...)	28.27[b]	93.33 (81.16)[a]	19.43	10.26[a]
Regime-6 (2,2,2,4,6,6.....)	31.40[a]	100.00 (90.00)[a]	19.07	10.48[a]
SEm±	**0.964**	**6.253**	**0.242**	**0.352**
CD at 5%	**2.797**	**18.147**	**NS**	**1.022**
CD at 1%	**3.700**	**24.505**	**NS**	**1.380**

Means compared using CD at 0.05
Means followed by the same letter in the column are not significantly different from each other
Values between parentheses are arc sin transformed
Values are average of 3 replications each
NS, F test is not significant
* Average number of *T. castaneum* larvae offered in each regime.

Survival during larval-cocoon period was significantly lower for Regime-1, (one larva per day for the entire period) which was 60%, while survival among all other five regimes was statistically not different; it ranged from (93-100%). Larval cocoon developmental period for all regimes ranged from (18.80-19.60 days) and all six regimes were statistically at par. Cocoon weight was lower (6.58mg) for Regime-1 and it was significantly different from all other treatments. Highest cocoon weight (10.48mg) was observed in Regime-6 and it was statistically at par with Regimes (4 and 5) but, different from others. Cocoon weight for the other two Regimes (2 and 3) was statistically not different from each other (8.96 and 9.21), respectively.

The average numbers of *T. castaneum* larvae given in each Regime were also significantly different from each other and each treatment assumed a different statistical rank. The average numbers of larvae in different Regimes were: Regime-1 = 9.30, Regime-2 = 15, Regime -3 = 20.05, Regime-4 = 23.13 1, Regime-5 = 28.27 and Regime-6 = 31.40 larvae.

4.4.3.3 Standardization of offering interval

Results on effect of prey (*T. castaneum* larvae) offering interval on larval-cocoon survival, developmental period and cocoon weight of the predator was presented in Table 18. Six intervals (Daily, one day, 2 days, 3 days, 5 days and given once at starting day) were tested. Statistical analysis revealed significant difference ($P \leq 0.05$) for developmental period and for cocoon weight, but for per cent survival was not significant.

Per cent survival ranged from (73.33-100%) for different treatments. Larval-cocoon developmental period was shorter (18.63 days) for T_3 (two days interval) and it was statistically at par with other treatments except T_5 (5 day interval) which gave longer (19.47 days) developmental period. Cocoon weight was highest (11.16 mg) also in T_3 and it was statistically at par with T_1 (daily offering), T_2 (one day interval) and T_4 (3 days interval) but, significantly different from others. On the other hand lowest cocoon weight (6.83 mg) was observed in T_6 (prey given once) and it was significantly different from all other intervals. From the above mentioned results we can conclude that 1-3 days interval was the optimal period to offer *T. castaneum* larvae for feeding *M. boninensis.*

4.4.3.4 Effect of prey storage on immature stages of *M. boninensis*

Results on the effect of cold storage of *T. castaneum* larvae on survival, developmental period of larval-cocoon stage and cocoon weight are presented in

Table 18. Survival (%), developmental period (neonate larva- adult, days), and cocoon weight of *M. boninensis* offered *T. castaneum* larvae at different intervals

Treatment	Survival (%)	Developmental period (neonate-adult) (days)	Cocoon weight (mg)
T1 (Daily)	93.33 (81.19)	18.95^{ab}	10.30^{b}
T2 (1 day interval)	100.00 (90.05)	18.73^{a}	10.46^{ab}
T3 (2 day interval)	93.33 (81.19)	18.65^{a}	11.16^{a}
T4 (3 day interval)	100.00 (90.05)	18.93^{ab}	10.47^{ab}
T5 (5 day interval)	100.00 (90.05)	19.47^{b}	10.13^{b}
T6 (given once)	73.33 (64.28)	19.14^{ab}	6.83^{c}
SEm±	**7.88**	**0.192**	**0.283**
CD at 5%	**NS**	**0.556**	**0.822**
CD at 1%	**NS**	**0751**	**1.109**

Means compared using CD at 0.05
Means followed by the same letter in the column are not significantly different from each other
Values between parentheses are arc sin transformed
Values are average of 3 replications each
NS, F test is not significant.

A. Full grown Larvae

B. Younger larvae

Plate 5. Full grown and younger larvae of *T. castaneum* incubated for one week at 26°C and 65% RH

Plate 6. Larvae of *M. boninensis* feeding on full grown *T. castaneum* larvae

Table 19. Statistical analysis showed significance (P≤0.05) for survival, developmental period as well as for cocoon weight.

Treatments of storage periods are: T_1 (8 weeks), T_2 (6 weeks), T_3 (4 weeks), T4 (2 weeks), T_5 (1 week), T_6 (fresh at starting day), T_7 (daily fresh).

Larval-cocoon survival was highest (93.33%) in T_6 which was statistically at par with T_4, T_5 and T_7, but significantly different from other (longer storage treatments). On the other hand lowest per cent survival (40) was observed in T_1 and T_2 which were not significantly different from T_3, T_4 and T_5.

Larval-cocoon period was shortest (18.12 days) in T_7 and it was statistically at par with T_6 but, significantly different from others (longer storage treatments). The longest larval-cocoon developmental period was recorded for T_2 (23.98 days), which was also statistically at par with T_1, T_3 and T_4. For cocoon weight the highest value (10.30 mg) was observed in T_6 and it was not significantly different from T_7 but, significantly different from others. On the other hand the lowest cocoon weight (8.06 mg) was observed in T_2 which was also statistically at par with T_3 and T_5.

Depending on these results we can conclude that *M. boninensis* larvae can feed on and complete their development on *T. castaneum* larvae cold stored up to 8 weeks. Nevertheless, as the storage period increased beyond one week these parameters gradually affected. Best performance was obtained on fresh killed and fed larvae or fresh fed on the first day then the same stock stored for the rest of the larval period.

4.5 Acceptability of Original Prey

Results on acceptability of *M. boninensis* for original prey after eleven generations of continuous rearing on factitious laboratory prey, *T. castaneum* larvae showed that the two field preys tested; the mustard aphid, *L. erysimi* and the mealybug, *Phenacoccus solani* were accepted by the predator. The predator completed its development on either of them. Table 20 shows the survival, developmental period and cocoon weight of the predator on either of them.

4.6 Cost of Production

The cost of production of *M. boninensis* on *C. cephalonica* eggs and *T. castaneum* larvae was calculated on the basis of costs of producing the prey and costs directly related to the predator. Details of costs involved in the production of the preys, *C. cephalonica* eggs and *T. castaneum* larvae are presented in Appendix IV and V, respectively.

Table 19. Survival (%), developmental period (neonate larva- adult, days), and cocoon weight of *M. boninensis* offered *T. castaneum* larvae cold stored for different periods

Treatment	Survival (%)	Developmental period (neonate-adult) (days)	Cocoon weight (mg)
T1 (8 weeks)	40 (38.87)^{c}	22.67^{bc}	8.42^{b}
T2 (6 weeks)	40 (38.87)^{c}	23.98^{c}	8.06^{c}
T3 (4 weeks)	46.67 (43.10)^{bc}	23.25b^{c}	8.12^{c}
T4 (2 weeks)	73.33 (64.26)^{abc}	23.67b^{c}	8.50^{b}
T5 (1 week)	66.67 (66.7)^{abc}	21.71^{b}	8.29^{bc}
T6 (fresh at starting day)	93.33 (81.19)^{a}	18.95^{a}	10.30^{a}
T7 (daily fresh)	86.67 (72.33)^{ab}	18.12^{a}	9.86^{ab}
SEm±	**10.73**	**0.684**	**0.494**
CD at 5%	**31.15**	**1.985**	**1.435**
CD at 1%	**NS**	**2.681**	**1.938**

Means compared using CD at 0.05
Means followed by the same letter in the column are not significantly different from each other
Values between parentheses are arc sin transformed
Values are average of 3 replications each
NS, F test is not significant.

Table 20. Survival, developmental period from neonate larvae to adult and cocoon weight of *M. boninensis* reared on *Lipaphis erysimi* and *Phenacoccus solani*

Prey	Survival (Neonate-adult) (%)	Developmental period (neonate-adult) (days)	Cocoon weight (mg)
Lipaphis erysimi	83.33	20.33±0.23	10.00±0.22
Phenacoccus solani	76.67	21.39±0.34	8.53±0.21

Results revealed that the cost of producing 1cc of *C. cephalonica* eggs was Rs. 17.26, while the cost of producing 1g of *T. castaneum* larvae was Rs. 3.57. For the production of *M. boninensis*, when *C. cephalonica* eggs were used as prey, the cost of producing 1,000 eggs of the predator was Rs. 15.91 (Appendix VI). However, when *T. castaneum* larvae were used as prey, the cost of producing 1,000 eggs was Rs. 7.36 (Appendix VII).

DISCUSSION

Trash-carrying chrysopids have attracted considerable attention world-wide in recent years for mass-production and use in biological control programmes. This is because of the advantage of protection against intraguild predation and prey alike attributed to camouflage conferred by the trash-package of the larva. *Mallada boninensis* is an important predator in this group; it is of wide spread distribution and has a great potential in controlling a large number of insect pests and mites in different crops and cropping systems. The present investigation is focused on search of a suitable laboratory host/prey which is less laborious, cost effective and causes no hazards to human health.

The results obtained on screening of suitable prey, effect of continuous rearing on the same prey on biological attributes of the predator, construction and comparison of life table statistics of the predator on the suitable preys, standardization of the prey and the cost of production are discussed in the succeeding paragraphs.

5.1 Screening of Prey for Mass production of *M. boninensis*

5.1.1 Influence of prey species on immature stages of *M. boninensis*

Results on acceptability of eight prey species by the larvae of *M. boninensis* showed that eggs of the red cotton bug, *Dysdercus Koenigii* and larvae of *Spilosoma obliqua* were not accepted. All predator larvae reared on these died within one to two days, during the first instar. The physical structure of the chorion of the bug egg and the spines (hairs) of *S. obliqua* larva may be the reason behind this unacceptability or some chemical deterrents may be involved. Kabissa *et al.* (1995) reported high larval mortality of the predator when reared on larvae of *Helicoverpa armigera*. However, no other reports are available with respect to these hosts.

Larvae of *Trogoderma granarium* were poorly accepted by *M. boninensis.* All larvae of the predator reared on these died during the larval period and no even a single larva reached the pupal stage, although some of them lived as larvae up to 22 days. Viji and Gautam (2005a) reported the suitability of *T. granarium* larvae for another chrysopid, *Chrysoperla carnea* but, no previous reports on this prey for *M. boninensis.* The other five preys; *Corcyra cephalonica* eggs, *Lipaphis erysimi* nymphs and adults,

Maconellicoccus hirsutus ovisacs and nymphs, *Tribolium castaneum* larvae and *T. castaneum* pupae were accepted by the predator but, they showed different effects on the survival and development of the predator. For overall survival from neonate larva to adult emergence, *C. cephalonica* eggs, *L. erysimi* nymphs and adults, and *T. castaneum* larvae were found suitable. Rearing this predator on *T. castaneum* larva or pupa is being reported for the first time. The predator survival was poor on *T. castaneum* pupa and *M. hirsutus* ovisac and nymph. Besides that high proportion of the adults emerged from larvae reared on them were malformed and on *T. castaneum* pupae high per cent of larvae pupated without forming cocoons. So, all these signs were indication of unsuitability of the prey. Nehare *et al.* (2004) reported that *C. cephalonica* egg was the most suitable prey for survival of *M. boninensis* out of many preys including *L. erysimi.* Mani and Krishnamoorthy (1990) reported survival of *M. boninensis* (82-90%) on mealybugs, *Ferrisia virgata, Planococcus citri* and *P. lalicinus*.

Prey species significantly affected larval and cocoon period. Shortest larval and cocoon periods were recorded on *C. cephalonica* eggs which is in conformity with Lee and Shih (1981) and Mani and Krishnamoorthy (1989), followed by *T. castaneum* larva, while the longest period was on *T. castaneum* pupa followed by *M. hirsutus* ovisac and nymph.

Result indicated that *C. cephalonica* eggs, *L. erysimi* nymphs and adults, and *T. castaneum* larvae were the best and statistically at par. The cocoon weight on these hosts ranged between 10.33-10.86mg. Lowest cocoon weight was obtained from larvae reared on *M. hirsutus* ovisacs and nymphs followed by *T. castaneum* pupae, 8.22 and 8.55mg, respectively. These latter two were statistically different from the former three. Cocoon weight implies the nutritional status of the prey and weight gain. However, no previous reports hitherto are available about cocoon weight of this predator on any prey. It may be concluded that *C. cephalonica* eggs, *T. castaneum* larvae and *L. erysimi* nymphs and adults were suitable for the survival development and body weight gain of *M. boninensis* than *T. castaneum* pupa and *M. hirsutus* ovisac and nymph.

5.1.2 Influence of prey species on adult longevity and fecundity

Depending on the performance of the predator on the five preys during immature stages, *M. hirsutus* was excluded and discontinued for the adult stage parameters due to

weak performance during immature stages, malformed and shortage of sufficient predator adults reared on it.

Observations on adult parameters were made on *C. cephalonica* eggs, *T. castaneum* larvae, *L. erysimi* nymphs and adults, and *T. castaneum* pupae. Average male longevity for the four preys revealed no significant difference and ranged between 33.5 days for *T. castaneum* pupae and 43 days for *C. cephalonica* eggs which is in agreement with Brettell (1979) who reported a shorter male longevity (21 days) on *Aphis fabae* nymphs. Joshi and Yadav (1990) reported a male longevity of 27.36 days on *C. cephalonica* eggs, while Lee and Shih (1981) found a longevity period of 43 days on *P. psylloptera* nymphs. Chen *et al.* (1989) found longevity of 61.8 days on larvae of citrus leaf miner, *P. citrella*, while Shivankar and Singh (1998) reported a male longevity of only 7-15 days on *P. citrella.*

Highest female longevity (57.67 days) and oviposition period (48 days) were expressed by adults reared as larvae on *C. cephalonica* eggs followed by those reared as larvae on *T. castaneum* larvae (46.17 and 39 days), respectively. These two parameters on the two prey species were statistically at par. On the other hand longevity on *T. castaneum* pupae and *L. erysimi* nymphs and adults were statistically at par and also not significantly different from that on *T. castaneum* larvae. These results were in line with the report of Lee and Shih (1981), a female longevity of 47.9 days on *P. psylloptera* nymphs. Brettell (1979) reported a female longevity of 31 days. Joshi and Yadav (1990) found a female longevity of 64.8 days on *C. cephalonica* eggs, while Shivankar and Singh (1998) found a female longevity of 35 days on the same host. Chen *et al.* (1981) reported a female longevity of 101 days on larvae of *P. citrella*, while Rao *et al.* (2003) reported a female longevity of 22.4-27.9 on *P. citrella.*

Pre-oviposition period was shorter on *T. castaneum* pupae (4.33 days) followed by *T. castaneum* larvae (4.83 days) and were statistically at par with each other. On the other hand the pre-oviposition period was longer on *L. erysimi* nymphs and adults (6.17 days) followed by *C. cephalonica* eggs (6 days). Lee and Shih (1981) and Joshi and Yadav (1990) reported pre-oviposition period of 4-11 days for *M. boninensis* reared on *P. psyloptera* nymph and *C. cephalonica* eggs, respectively. Shivankar and Singh (1998) reported pre-oviposition period of 6-8 days. From these results it may be agreed that type of the prey significantly influenced the pre-oviposition period and the prey

T. castaneum larva and pupa was advantageous in this aspect through nutritive value or offering other stimulus to the predator.

Considering fecundity (eggs/female) the order was *C. cephalonica* eggs 652.17 >*T. castaneum* larvae 566.83 > *L. erysimi* 410.33 > *T. castaneum* pupae 387.5. The first three were statistically at par. Lee and Shih (1981) reported a fecundity of 512.3 eggs on *P. psylloptera* nymphs. Chen *et al.* (1989) reported fecundity of 400 eggs on *P. citrella*. Joshi and Yadav (1990) found 431 as average fecundity on *C. cephalonica* eggs, while Shivankar and Singh (1998) reported female fecundity of 200-300 eggs. However, Rao *et al.* (2003) reported fecundity of only 95.4-115.7 eggs on *P. citrella*. So, the fecundity obtained during this study on *C. cephalonica* eggs and *T. castaneum* larvae was higher than all previous reports on fecundity of this predator and this might be due to conditions of rearing and the strain of the predator used in addition to the prey species.

Depending on the above mentioned discussion on the influence of the prey on adult longevity and fecundity it is concluded that *C. cephalonica* eggs and *T. castaneum* larvae were more suitable for *M. boninensis* than the two other preys, *T. castaneum* pupae and *L. erysimi* nymphs and ovisacs, provided that they sustained high predator longevity, oviposition period and fecundity, Besides, this was their positive effect on immature stages *i.e.* high survival per cent, shorter larval and cocoon period and heavier cocoons. *T. castaneum* pupae and *L. erysimi* nymphs though they produce relatively longer developmental period and lighter cocoon weight but, fecundity of the predator on them was good in comparison to many previous reports.

5.2 Continuous Rearing of *M. boninensis* on *C. cephalonica* Egg and *T. castaneum* Larva

C. cephalonica egg and *T. casaneum* larva were identified out of eight preys as most promising for laboratory rearing of *M. boninensis*. Effect of continuous rearing of *M. boninersis* on these two preys up to generation 11^{th} (G_{11}) was discussed in the following pages.

5.2.1 Influence of prey and generation on immature stages of the predator

Per cent mortality of immature stages of *M. boninensis* was significantly lower on *T. castaneum* larvae than on *C. cephalonica* eggs. It was observed that on *T. castaneum*

larvae; the morality was lower in latter generations than in earlier generations. Mortality of eggs, first instar larvae, pupation failure and malformed adults was lower on *T. castaneum* larvae than on *C. cephalonica* eggs. It was observed that as the generation progressed adult malformation on *T. castaneum* larvae decreased, while on *C. cephalonica* eggs there was no clear trend.

Previous work (Kabissa *et al.*, 1989, Joshi and yadav, 1990; Shivankar and Singh, 1998; Rao *et al.*, 2003) showed that mortality of different stages of *M. boninensis* varied on different preys. Kabissa *et al.* (1989) reported high larval mortality of *M. boninensis* (52.9 and 82.6%) on *H. armigera* larvae and *Aphis gossypii* nymphs, respectively. Viji and Gautam (2005a) found similar results to the present study on another chysopid, *C. carnea* that mortality of immature stages was lower on *T. castaneum* larvae than on other preys including *C. cephalonica* eggs.

Average developmental period (egg to adult) of *M. boninensis* in different generations was shorter (20.58 days) on *C. cephalonica* egg than on *T. castaneum* larva (22.65 days). Similar results were indicated by other reports (Lee and Shih, 1981; Mani and Krishnamoorthy, 1989; Nehare *et al.*, 2004). However, Joshi and Yadav (1990) reported a shorter larval period on *B. tabaci* than on *C. cephalonica* eggs. Lee and Shih (1981) reported that the type of prey influenced the life cycle of *M. bonnensis* and found a shorter life cycle on *C. cephalonica* eggs as compared to *P. psylloptera* nymphs. Mani and Krishnamoorty (1989) found that the development of *M. boninensis* was completed in 21.85 days on *C. cephalonica* eggs and 25.5 days on *M. hirsutus*. Lopez *et al.* (1999) reported that eggs of the moths *Anagasta Kuehniella* and *Sitotroga cerealella* gave substantially and significantly faster development when used for rearing trash-carrying chsysopids within the genus *Ceraeochrysa* than did a diet of *Myzus persicae* .

On either of the two preys there was no clear trend throughout generations for increasing or decreasing developmental period but, variations among some generations were detected. Mackaur (1972) and Jones *et al.* (1978) mentioned that insects kept in mass culture for long time are known to deteriorate in biological and behavioural attributes. Variations in developmental period on the two preys was mainly due to variations in larval and cocoon period which both were significantly shorter on *C. cephalonica* eggs but, in egg incubation period there was no clear consistent variation between the two preys. Mani and Krishnamoorthy (1989) found larval period on

C. cephalonica eggs of 9.25 days and 11.30 days on *M. hirsutus*, while the cocoon period was 8.35 and 10.10 days on the rice moth and mealybug, respectively.

During this study the prepupal period was found to be 3-4 days with an average of 3.21 ± 0.01 days. The prepupal period was determined by dissecting the cocoons (one day old cocoon). At dissection time all cocoons contained prepupae (pharate pupae) and they remained as prepupae up to 3-4 days then the larval skin shed and pupae appear. Earlier Joshi and Yadav (1990) reported that prepupal period in *M. boninensis* reared on *C. cephalonica* eggs was only 5-7 hours. This period of 5-7 hours may be the time of cocoon formation but inside the cocoon the prepupa (pharate pupa) remained for 3-4 days in the present study.

The average cocoon weight of all generations was higher on *C. cephalonica* eggs (10.68mg) than on *T. castaneum* larvae (10.37mg), but during latter generations (G_8 and G_{10}) the weight was higher on *T. castaneum* larvae. This may be due to adaptation to the prey after several generations. In case of cocoon reared on *C. cephalonica* eggs no clear effect of generation on the weight of cocoon was observed.

The weight of cocoon reared on *C. cephalonica* eggs may be physically affected by some *C. cephalonica* eggs incorporated in the formation of the cocoon because of their small size but, *T. castaneum* larvae can easily be removed from the surface of the cocoon. No previous reports on the weight of cocoon of *M. boninensis* are available. Viji and Gautam (2005b) reported higher cocoon weight (12.50-8.88 mg) for *C. carnea* when reared on *T. castaneum* larvae as compared to *C. cephalonica* eggs and other preys.

5.2.2 Influence of prey and generation on biological attributes of adult *M. boninensis*

Adult male wing expanse was not affected by the prey or the generation but, the interaction between prey and generation was significant. Male wing expanse was higher on *T. castaneum* larvae in latter generations (G_8 and G_{11}) while in earlier generations (G_1, G_4 and G_5) the wing expanse was higher on *C. cephalonica* eggs. Male wing expanse during different generations ranged from (25.50-26.45 mm) on *C. cephalonica* eggs and from (25.55-26.35 mm) on *T. castaneum* larvae. Joshi and Yadav (1990) reported average male wing expanse of 26.30 mm.

For female wing expanse overall mean of generations on either prey revealed no significant difference but, generation had a significant effect. On *T. castaneum* larvae the wing expanse increased as generation proceeded (G_8, G_{10}, and G_{11}), while on *C. cephalonica* eggs in the earlier generations (G_1, G_2 and G_4) the wing expanse was higher and decreased in latter generations (G_8, G_{10} and G_{11}). On *T. castaneum* larvae wing expanse ranged from 27.35mm in G_4 to 29.00mm in G_{10}, while on *C. cephalonica* eggs it ranged from 27.91mm in G_{10} to 28.55mm in G_7 which is not in agreement with Joshi and Yadav, (1990) who reported female wing expanse of 31.30mm. Rearing conditions and strain of the predator used may be the cause behind this variation in female wing expanse between the two studies.

Average male longevity was significantly higher on *T. castaneum* larvae than on *C. cephalonica* eggs, 41.73 days as against 37.15 days, respectively. Male longevity on both preys reached its maximum during latter generations G_{10} on *T. castaneum* larvae and G_{11} on *C. cephalonica* eggs. On *T. castaneum* larvae there was a clear trend of increased male longevity from G_1 up to G_{10} excluding G_3, but on *C. cephalonica* eggs fluctuation was clear from one generation to another. The range of average male longevity on *T. castaneum* larvae in different generations was (30.33 days in G_3 to 84.67 days in G_{10}), while on *C. cephalonica* eggs it was (31.33 days in G_2 to 45.75 days in G_{11}). Previous literature indicated different periods for male longevity on different preys, (Brettell, 1979; Lee and Shih, 1981; Chen *et al.*, 1989; Rao *et al.*, 2003; Nehare *et al.*, 2004), they reported male longevity on different preys as 21, 43, 61.8, 15, 22.4 and 37.06 days, respectively. Male longevity in G_{10} and G_{11} on *T. castaneum* larvae was higher than all these values which indicate the suitability of *T. castaneum* larvae for this predator.

Considering female longevity, results indicated significantly higher mean female longevity for all generations (50.66 days) on *T. castaneum* larvae than on *C. cephalonica* eggs (44.95 days). Generation also had a significant effect on female longevity. In earlier generations (G_1, G_3 and G_4) female longevity was higher on *C. cephalonica* eggs while, in latter generations (G_8, G_{10} and G_{11}) female longevity was significantly higher on *T. castaneum* larvae and is supported by Viji and Gautam (2005a) who found that male and female longevity of *C. carnea* reared on *T. castaneum* larvae was higher than that reared on *C. cephalonica* eggs and other preys.

The range of average female longevity on *T. castaneum* larvae in different generations was (39.58 days in G_4 to 71.75 days in G_{11}), while the range on *C. cephalonica* eggs was (38.92 days in G_{10} to 51.08 days in G_1). An array of literature also indicated variations in female longevity (Brettell, 1979; Lee and Shih, 1981; Chen *et al.,* 1989; Joshi and Yadav, 1990; Shivankar and Singh, 1998; Rao *et al.,* 2003; Nehare *et al.,* 2004); they reported female longevity of 31.4, 47.9, 101.7, 64.8, 35, 27.9 and 53.22 days, respectively. Female longevity in the present study on *T. castaneum* larvae in the last two generations (G_{10} and G_{11}) also exceeded all of the previous reports except that of 101.7 days found by Chen *et al.* (1989) in China for *M. boninensis* reared on larvae of citrus leaf miner *P. citrella.*

Pre-oviposition period was significantly shorter on *T. castaneum* larvae (4.93 days) than on *C. cephalonica* eggs (5.49 days), while generation has no clear effect on preoviposition period on either of the two preys. Earlier Lee and Shih (1981) reported a range of pre-oviposition period (4-11 days), Joshi and Yadav (1990) found an average pre-oviposition period of 9.9 days, while Shivankar and Singh (1998) reported a period of 6-8 days and Nehare *et al* (2004) reported an average pre-oviposition period of 4.4 days on nymphs of *A. woglumi.* So, the type of prey had a clear effect on preoviposition period. That may be attributed to the nutritional condition during the larval period or other stimulating factor associated with the prey used.

Mean oviposition period of all generations was significantly higher (41.48 days) on *T. castaneum* larvae than on *C. cephalonica* eggs (35.03 days). Generation also had a significant effect on oviposition period on either of the two preys. It was clear that on *C. cephalonica* eggs the oviposition period was longer in earlier generations (G_1 and G_3) than in latter generations (G_7, G_{10}, G_{11}), while on *T. castaneum* larvae the oviposition period increased considerably in latter generations (G_{10} and G_{11}). On *C. cephalonica* eggs the oviposition period during different generations ranged from (27.92 days in G_{10} to 42.25 days in G_1), while on *T. castaneum* larvae it ranged from (30.83 days in G_5 to 62.08 days in G_{11}). Previous reports on oviposition period of this predator are available mainly on *C. cephalonica* eggs. Lee and Shih (1981) reported an oviposition period ranging between 11-80 days on *P. psylloptera*; Joshi and Yadav (1990) reported 36.9 days, while Nehare *et al.* (2004) reported 46.6 days on *C. cephalonica* eggs. No previous reports are available for female longevity of this predator on *T. castaneum* larvae. Present

studies are supported by Viji and Gautam (2005a) that oviposition period of *C. carnea* reared on *T. castaneum* larvae was significantly higher than that reared on *C. cephaalonica* eggs and other preys.

For female fecundity, prey generation and interaction between prey and generation had a significantly high effect. Fecundity on *T. castaneum* larvae was significantly higher (544.15 eggs/female) than on *C. cephalonica* eggs (406.56 eggs/ female). Moreover, the fecundity on *T. castaneum* larvae was higher than on *C. cephalonica* eggs in all generations except G_4. Fecundity on *C. cephalonica* eggs ranged between 267.83 eggs/female in G_{10} to 579.50 eggs/female in G_1 and there was a general trend of decreased fecundity as generation proceeded. This is in agreement with Gautam (1994c) that axenic rearing of *C. carnea* on frozen eggs of *C. cephalonica* revealed reduction in fecundity by the end of 20th generation. On the other hand fecundity on *T. castaneum* larvae during different generations ranged between 401.83 eggs/female in G_6 and 876.75 eggs/female in G_{10} which was also statistically at par with G_{11}. Female fecundity on *T. castaneum* larvae though it was higher almost in all generations, moreover it increased significantly in the two last generations (G_{10} and G_{11}) indicating the suitability of *T. castaneum* larvae to sustain the longevity and fecundity of this predator for many successive generations.

Previous records of fecundity for this predator showed great variation on different preys. Lee and Shih (1981) reported fecundity of 512.3 eggs/female, Chen *et al.* (1989) found fecundity of 400 eggs/female, Joshi and Yadav (1990) reported 431 eggs/female as average fecundity, Shivankar and Singh (1998) reported a range of 200-300 eggs/ female, Rao *et al.* (2003) reported fecundity of only 95.4-115.7 eggs/female. Comparing these reports which depend on single generation each, to the present study we can conclude that, this study revealed an unprecedented record of female fecundity for *M. boninensis* (544.15 eggs/female) as an average fecundity of ten generations and 876.75 eggs/female as a mean fecundity for one generation (G_{10}). Therefore, *T. castaneum* larva was a superior prey for mass production of *M. boninensis.* In this context Viji and Gautam (2005a) reported that *C. carnea* fed on *T. castaneum* larvae had a high fecundity than on an array of other prey species they tested including the traditional prey, *C. cephalonica* egg.

Egg hatchability on the two prey species was high during the first week of oviposition (82% on *C. cephalonica* eggs and 93% on *T. castaneum* Larvae). During subsequent weeks hatchability decreased gradually reaching 65% on *C. cephalonica* eggs and 72% on *T. castaneum* larvae by the 7th week of adult age. Unhatchability was due to infertile eggs (eggs remained green) or death of embryo before hatching (eggs changed to brown or black). Death of embryo was consistently greater than infertility on both preys. So, egg hatchability was higher on *T. castaneum* larvae. Shivankar and Singh (1998) reported egg hatchability of 85-100% in laboratory culture of *M. boninensis* but they did not mention the age of female adults for this hatchability.

Depending on the above it may be inferred that continuous rearing of *M. boninensis* on *T. castaneum* larvae and *C. cephalonica* eggs up to eleven generations revealed the following comparative advantages and disadvantages for the two preys.

T. castaneum larvae were more suitable for survival and reproduction of the predator than *C. cephalonica* eggs. Survival of immature stages, male and female longevity, oviposition period and fecundity were significantly higher on *T. castaneum* larvae. Pre-oviposition period was shorter and sex ratio was in the favour of females on *T. castaneum* larvae. Moreover, biological attributes like fecundity and longevity were getting better as generation advanced. There was no previous literature about rearing this predator on *T. castaneum* larvae, these results were in agreement with findings of Viji and Gautam (2005a) using *T. castaneum* larvae for producing another chrysopid, *C. carnea.*

On the other hand on *C. cephalonica* eggs the developmental period of the predator (egg to adult) was shorter, cocoon weight was higher but, this was not reflected into bigger size adults (wing expanse was not so), longevity and fecundity were lower, pre-oviposition period was longer and sex ratio was in the favour of males than females. Moreover, during latter generations fecundity decreased drastically, indicating deterioration of these attributes. Similar results were reported by Jones *et al.* (1978) for continuous rearing of *C. carnea* in mass culture for many generations resulting in decreased longevity, fecundity, searching ability and feeding as the number of generations in mass culture increased. Also Hegde and Kulkarni (2005) reared *C. carnea* up to 24th generation on eggs of *C. cephalonica.* They observed slow decline in characters especially hatchability and fecundity from G_1 to G_{24}.

5.3 Life Tables

The cohort life and fecundity tables for *M. boninensis* were constructed on generation eight (G_8) after continuous rearing on *C. cephalonica* eggs and *T. castaneum* larvae from G_1. The aim was to estimate the comparative overall effects of these two preys on the survival, development, reproduction and the final growth rate of the predator population, so as to assess their comparative advantages as laboratory prey for mass-production of this predator.

Results indicate that survivorship of the predator on *T. castaneum* larvae was higher than on *C. cephalonica* eggs, mainly due to higher mortality during the egg stage on C. *cephalonica* eggs. Previous work (Shivankar and Singh, 1998; Nehare *et al.*, 2004)) showed that mortality of different stages of *M. boninensis* varied on different preys. The average immature developmental period (egg to oviposition) was slightly shorter on *C. cephalonica* eggs (25.3 days) as against 26 days on *T. castaneum* larvae and is in agreement with Lee and Shih (1981).

For evaluation of the effects of the prey on all components of the biological attributes, life table statistics show the comparison. The gross reproductive rate (GRR), net reproductive rate (R_o), intrinsic rate of natural increase (r_m) and finite rate of increase (λ) for the predator were higher on *T. castaneum* larvae than on *C. cephalonica* eggs. Though mean generation time (T) was about one day shorter on *C. cephalonica* eggs (33.83 days) than on *T. castaneum* larvae (34.78 days), the doubling time (DT) was shorter (4.69 days) on *T. castaneum* larvae than on *C. cephalonica* eggs (4.75 days). The net reproductive rate (R_o) was 171.43 females/female/generation on *T. castaneum* larvae, while it was 139.12 females/female/generation on *C. cephalonica* eggs.

According to these statistics the population of *M. boninensis* multiplied 171.43 times in a generation time of 34.78 days on *T. castaneum* larvae, while it multiplied 139.12 times on *C. cephalonica* eggs in a period of 33.83 days. Comparing the multiplication rate per unit of time; the intrinsic rate of natural increase (r_m) was 0.1478956 and 0.1458789 females/female/day, and the finite rate of increase (λ) was 1.1593 and 1.1571 females/female/day on *T. castaneum* larvae and *C. cephalonica* eggs, respectively. Jervis *et al.* (2005) stated that, prey species can influence the intrinsic rate of natural increase of predators.

Lee and Shih (1981) estimated r_m, R_o and T for *M. boninensis* reared on *P. psylloptera* as 0.0964, 181.5 and 54.2, respectively, but the estimates of Bakthavatsalam *et al.* (1994) for these statistics for *M. boninensis* reared on *C. cephalonica* eggs were different. They estimated r_m, R_o and T as 0.3329, 191.71 and 17.999, respectively. This estimation of generation time (T) as 17.999 was too low and this period is not sufficient even to complete the developmental period of immature stages of the predator (development from egg to oviposition is not less than 25 days) and oviposition period of adult can be up to 36.9-46.6 days (Nehare *et al.* 2004; Joshi and Yadav, 1990). Moreover, the calculation of r_m and R_0 depends on generation time (T). Generation time is the mean period elapsing between the birth of parents and the birth of offspring (Krebs, 1972).

Since, the gross reproductive rate (GRR), net reproductive rate (R_o), intrinsic rate of natural increase (r_m) and finite rate of increase (λ) of the predator were higher on *T. castaneum* larvae than on *C. cephalonica* eggs, and the doubling time was shorter on *T. castaneum* larvae, we may thus conclude that *T. castaneum* larvae were comparatively more suitable than *C. cephalonica* eggs as a laboratory prey for the predator, *M. boninensis.*

5.4 Standardization of the Prey, *T. castaneum*

T. castaneum larvae were found suitable for survival development and reproduction of *M. boninensis* in the laboratory. Therefore, its rearing techniques and handling were standardized so as to provide a continuous supply of prey in an appropriate form, which can easily be managed with less labour effort and low cost.

5.4.1 Effect of density of adult beetle on production of larvae

The larvae of *T. castaneum* became full-grown in 18-19 days from the day of adult release at 30±1°C and 60±5% RH and adult continued to reproduce up to 4-5 months which is supported by Pajni and Virk (1982).

Results on adult density showed that maximum number (1554.33) of full-grown larvae was produced by adult density of 200/100g of wheat flour which was statistically at par with the number of larvae produced by adult densities of 140 and 260. Considering the total biomass of larvae produced; the highest biomass (3.81g) was produced by density of 140 adults and it was also statistically at par with biomass produced by

density of 200 adults. All other lower or higher densities of adults produced less biomass as well as less number of larvae. The reason was that, in case of lower densities the quantity of flour was not fully utilized because of low number of larvae produced, while, in case of higher densities overcrowding, shortage of food, competition and cannibalism reduced the numbers as well as the biomass. Park *et al.* (1974) reported that larvae of *T. castaneum* were cannibalistic in nature, if there is shortage of food.

Density of adult, besides affecting the number of larvae produced and the total biomass it also influenced the weight per larva produced. All densities of adult from (10-140/100g flour) produced average weight of larva ranged from (2.5-2.38 mg/larva) and all these were statistically at par. Higher densities produced significantly and progressively lower weight larva as the density of adult increased. The optimum density of adult to produce maximum biomass with reasonable number and weight per larva in 100g of wheat flour was identified as 140 adults.

5.4.2 Quantification of adult beetle

In order to save effort and time in counting small sized and actively moving beetles, quantification of adult *T. castaneum* beetle was standardized by volume or weight. It was found that the number of adult beetle in 1ml volume was 246.64 ± 3.96 and the number of beetles in 100mg weight was 53.47±0.46 on an average, so the number of beetles/g approximately 534.7.

5.4.3 Standardization of *T. castaneum* larvae as prey for *M. boninensis*

5.4.3.1 Standardization of larval age

Survival and developmental period of immature stages of *M. boninensis* was found to be affected by the age of *T. castaneum* larvae used as prey. Full grown larvae were found more suitable than younger ones. Per cent survival of the combined larval and cocoon stage of the predator was significantly higher (96.30) on full-grown larvae than on younger ones (77.78). Larval-cocoon developmental period was significantly shorter (18.57days) on full-grown larvae than on younger ones (19.29 days) while the difference in the cocoon weight was not significant but, its average value also greater on full-grown larvae (10.73mg) as against 10.26mg on younger larvae.

Younger *T. castaneum* larvae were perishable and decay faster than full-grown larvae. It was observed that after freeze killing of the larvae the colour of younger started changing to dark and became soft during shorter period compared to older or full-grown ones. No previous literature was available about this aspect.

5.4.3.2 Standardization of numbers of prey

Results on the effect of number of *T. castaneum* larvae given per day per larva of *M. boninensis* in six feeding regimes showed that developmental period was not affected by the feeding regime. Regime-1 (one larva/larva/day for entire period) resulted in significant reduction in per cent survival of the larval-cocoon stage compared to other regimes as well as reduction in cocoon weight of the predator. Larvae kept on this regime became actively moving inside the tubes in search of food, an indication of starvation, particularly during the last two days of larval period, while this activity was not observed on the other five regimes.

Although per cent survival and developmental period on all other five regimes were not significantly different from each other, nevertheless, cocoon weight was significantly lower in Regime-2 and Regime-3. Regimes 4, 5 and 6 produced the highest rank of cocoon weight and were statistically at par. Therefore, we may conclude that, developmental period was not effected by the number of larvae offered per day. Regime-1 significantly reduced survival as well as cocoon weight indicating shortage of food and under nourished individuals. Regimes (2 and 3) significantly reduced the cocoon weight as compared to regimes (4, 5 and 6). Regimes (4, 5 and 6) were statistically at par for all three parameters taken.

From the economic point of view to avoid wastage of food regime 4 was the most appropriate. According to this regime the number of *T. castaneum* larvae needed/ predator larva ranged between (19-24) average 23.13 given (1, 1, 1, 2, 2, 2, 4, 4). Sarode and Sonalkar (1998) reported that density of *C. cephalonica* eggs significantly influence pupal weight of another chrysopid, *C. carnea.*

5.4.3.3 Standardization of prey offering interval

The prey, *T. castaneum* larva was given for feeding the predator after freeze killing so as to reduce the risk of feeding on the predator cocoon. If the already killed prey given once in sufficient quantity it was expected to perish or dry out. To reduce the

cost of handling and daily adding the prey results on prey offering intervals show the effect of six different intervals on survival, developmental period of larval-cocoon stage and weight of cocoon.

Per cent survival was not affected by the interval. The shortest developmental period and the heaviest cocoon weight were observed in the treatment of two days interval. Developmental period was longest in the five days interval. Cocoon weight was lowest when the prey was given once and it was significantly different from all other intervals. For cocoon weight no significant difference between daily offering, one day interval, 3 days interval or 5 days interval. Highest cocoon weight was obtained on two days interval and the cocoon weight decreased as we go to higher or lower interval.

These variations in the effects of offering interval may be due to variations in the moisture content of the prey appropriate for the predator; giving the prey once it might dry out or decay during the 8-10 days of larval development. Also killing and immediately offering the prey significantly reduced cocoon weight and that might be due to requirement of some preconditioning period for *T. castaneum* larvae after killing so as to be more suitable for feeding this predator. Three days interval was the most appropriate interval to produce good cocoon weight and reduce the handling by adding the prey 2-3 times during larval period of the predator.

5.4.3.4 Storage of the prey and its effect on the predator

High per cent survival, short developmental period and high cocoon weight were observed in T_6 (fresh at starting day) and T_7 (daily fresh). In all other treatments per cent survival decreased, developmental period increased and cocoon weight decreased as the storage period prolonged. Nevertheless, in all storage periods the predator completed its immature stage development and adults emerged.

So, we can conclude that storage of the prey, *T. castaneum* larvae beyond two weeks significantly reduced the cocoon weight and prolonged developmental period, while storage beyond four weeks besides affecting cocoon weight and developmental period it also significantly reduced per cent survival during larval-cocoon period. Gautam and Paul (1987) found that cold storage of an artificial diet for *Chrysopa seclestes* beyond 23 days significantly affected pupation of the predator. Gautam and Viji (2005b)

reported that cold storage of *T. castaneum* larvae resulted in increased larval period and decreased per cent adult emergence.

5.5 Acceptability of Original Prey by the Predator after Axenic Rearing

Results showed that *M. boninensis* had accepted the original preys, *L. erysimi* and *P. solani* after eleven generations of continuous rearing on factitious laboratory prey, *T. castaneum* larvae. The predator completed its development on the two preys, however, per cent survival of larval-cocoon stage and cocoon weight were lower on the mealybug than on the aphid and larval-cocoon developmental period was slightly longer on the mealybug. Mani and Krishnamoorthy (1989) reported that the developmental period of this predator on mealybugs was relatively longer. Therefore it may be concluded that contiuous rearing of *M. boninensis* up to eleven generations did not affect or alter the acceptability of the predator to its original field preys.

5.6 Cost of Production

Costs were categorized as fixed and variable costs, and accordingly the expenses of the prey as well as the predator were estimated. Results indicated that the cost of production of the predator was greatly influenced by the cost of the prey used for its rearing.

The cost of producing 1cc of *C. cephalonica* eggs was Rs. 17.26 and the cost of producing 1g of *T. castaneum* larvae was Rs. 3.37. Earlier Jalali *et al.* (2003) estimated the cost of producing 1cc *C. cephalonica* eggs as Rs.10.45. Variation between the two estimates was due to increase in prices of materials used between 2003 and 2006. For rearing 100 larvae of the predator on either of the two preys, a quantity of 5cc C. *cephalonica* eggs (Jalali *et al.,* 2003) or 5.7g *T. castaneum* larvae is required. The production cost of 1000 eggs of *M. boninensis* was estimated as Rs. 15.91 and Rs. 7.36 when reared on *C. cephalonica* eggs and *T. castaneum* larva, respectively. Low cost on *T. castaneum* larva was due to high survival and fecundity of the predator on *T. castaneum* larvae and low cost of production of *T. castaneum* larvae as compared to *C. cephalonica* eggs which is supported by Viji and Gautam (2005b) who found that the production cost of *C. carnea* on *T. castaneum* larvae was significantly cheaper than on *C. cephalonica* eggs.

SUMMARY

The green lacewing, *Mallada boninensis* is one of the important, widely distributed chrysopid predators. It has a great potential for use against a large number of insect pests of both horticultural and field crops in combination with other integrated pest management methods. This predator is normally mass-produced on frozen eggs of the rice moth, *Corcyra cephalonica* which is tedious to rear, expensive, and causes some health hazards to workers.

The present study was conducted to screen for a suitable laboratory host/prey which can easily be produced with lesser effort, less hazardous, less cost and can sustain the multiplication of the predator for many successive generations without deterioration of the progeny produced.

The salient findings of the study are summarized as follows:

❖ Out of eight prey species and/or stages screened during one generation of *M. boninensis*; eggs of *C. cephalonica* and larvae of *Tribolium castaneum* were found the most suitable for survival and development of immature stages as well as for adult longevity and fecundity.

❖ Eggs of the red cotton bug, *Dysdercus koenigii* and larvae of the moth, *Spilosoma obliqua* were not accepted by *M. boninensis* larvae for feeding, while the larvae of *Trogoderma granarium* were proved to be unsuitable for survival and development of this predator, since all larvae reared on them died during larval stage.

❖ Pupae of *T. castaneum* as well as ovisacs and nymphs of *Maconellicoccus hirsutus* though accepted by the predator and it completed its development on them; they resulted in poor survival of immature stages, produced lighter weight cocoons and high proportion of malformed adults.

❖ Nymphs and adults of the aphid, *Lipaphis erysimi* were accepted and proved suitable for survival, development and reproduction of *M. boninensis* but it is difficult to maintain its culture in the laboratory.

❖ Testing the suitable preys, *C. cephalonica* eggs and *T. castaneum* larvae in continuous rearing for eleven generations, *T. castaneum* larvae were found more suitable

for survival and reproduction of the predator than *C. cephalonica* eggs. Survival of immature stages, longevity of male and female, oviposition period and fecundity were higher on *T. castaneum* larvae. Pre-oviposition period was shorter and sex ratio was in the favour of females on *T. castaneum* larvae. Moreover, biological attributes like fecundity and longevity were getting better and better as generation advanced.

❖ On the other hand, on *C. cephalonica* eggs the developmental period of the predator (egg to adult) was shorter, cocoon weight was higher but this was not reflected into bigger size adult (wing expanse was not in the same order), longevity and fecundity were lower, pre-oviposition period was longer and sex ratio was in the favour of males than females. Moreover, during latter generations fecundity decreased drastically.

❖ The overall mean of all generations for mortality was significantly higher (30.21%) on *C. cephalonica* eggs as against 25.38% on *T. castaneum* larvae. Egg mortality was significantly lower (17.50) on *T. castaneum* larvae than on *C. cephalonica* eggs (22.41). Mortality in first instar larvae was significantly lower (7.16%) on *T. castaneum* larvae than on *C. cephalonica* eggs (11.68%). The highest per cent pupation failure (14.86) was detected in G_4 on *C. cephalonica* eggs as against 4.17 in G_2 on *T. castaneum* larvae. On *C. cephalonica* eggs, highest per cent malformation (18.25) was observed in G_{10}, while on *T. castaneum* larvae, the highest per cent malformed adult (9.73) was observed in G_2.

❖ Average developmental period (egg to adult) in *M. boninensis* was significantly shorter (20.58 days) on *C. cephalonica* eggs as against 22.65 days on *T. castaneum* larvae. Egg incubation period on these preys was not significantly different and ranged between 2.97-3.17 days. Larval developmental period on *C. cephalonica* eggs were significantly shorter (8.18 days) than on *T. castaneum* larvae (9.82 days). Cocoon period was also significantly shorter (9.45 days) on *C. cephalonica* eggs than on *T. castaneum* larvae (9.80 days).

❖ For cocoon weight the overall mean of generations was significantly higher (10.68mg) on *C. cephalonica* eggs as compared to those reared on *T. castaneum* larvae (10.37mg). Male and female wing expanse revealed no significant difference for prey but, in case of female wing expanse there was significant difference for generation and wing expanse increased significantly during latter generations on *T. castaneum* larvae *i.e* 27.45mm in G_1 and 29.00mm in G_{10}.

❖ Male longevity was significantly higher (41.73 days) on *T. castaneum* larvae than on *C. cephalonica* eggs (37.15 days). Longest male longevity (84.67 days) was observed in G_{10} on *T. castaneum* larvae. Female longevity on *T. castaneum* larvae was also significantly higher (50.56 days) than on *C. cephalonica* eggs (44.95 days). Highest female longevity on *T. castaneum* larvae (71.75 days) was observed in G_{11} while on *C. cephalonica* eggs the highest female longevity (51.08 days) was observed in G_1.

❖ Mean of all generations showed that preoviposition period was significantly shorter (4.93 days) on *T. castaneum* larvae than on *C. cephalonica* eggs (5.49 days), while oviposition period was significantly longer (41.48 days) on *T. castaneum* larvae than on *C. cephalonica* eggs (35.03 days).

❖ The overall mean of generations on the two preys shows that fecundity on *T. castaneum* larvae was significantly higher (544.15 eggs/female) than on *C. cephalonica* eggs (406.56 eggs/female). Fecundity on *T. castaneum* larvae was higher in all generations except G_5 and the difference was significant in five generations (G_2, G_6, G_8, G_{10} and G_{11}). Highest fecundity performance on *C. cephalonica* eggs (579.50 eggs/female) was expressed by G_1 while highest fecundity performance on *T. castaneum* larvae (876.75 eggs/female) was observed in G_{10}.

❖ The overall sex ratio for all generations was 1:0.90 (M:F) on *C. cephalonica* eggs and 1:1.08 (M:F) on *T. castaneum* larvae.

❖ Morphological differences of the last two abdominal segments in *M. boninensis* can be used to differentiate between male and female imago.

❖ Results on the age-specific cohort life tables of *M. boninensis* revealed that maximum female progeny/week was 63.08 and 65.93 female eggs/female/week on *C. cephalonica* eggs and *T. castaneum* larvae, respectively, produced during the 5th age-interval (28-35 days).

❖ The gross reproductive rate (GRR) was 225.42 females/female/generation on *C. cephalonica* eggs, while it was 265.54 females/female/generation on *T. castaneum* larvae. The net reproductive rate (R_0) was 139.12 and 171.43 females/female/generation on the two preys, respectively. Mean generation time (T) was 33.83 and 34.78 days on *C. cephalonica* eggs and *T. castaneum* larvae, respectively. The intrinsic rate of natural increase (r_m) was 0.1458789 and 0.1478956 females/female/day on the two preys,

respectively. The finite rate of increase (λ) was 1.1593 females/female/day on *T. castaneum* larvae, while it was 1.1571 on *C. cephalonica* eggs.

❖ Optimum number of *T. castaneum* adults to produce maximum biomass (3.81±0.07g) of larvae/100g wheat flour was found to be about 140 beetles and the number of larvae produced was 1545±29.67 with average weight/larva of 2.47mg.

❖ Quantification of adult *T. castaneum* beetles by volume or weight revealed that the average number of adult beetle in 1 ml volume equal 246±3.96 and the number of adult beetle in 100mg weight equal 53.47±0.46 (=534.7 beetles/g).

❖ Survival during larval cocoon period of the predator was significantly higher (96.30%) on full-grown larvae as against 77.78% on younger larvae and larval-cocoon developmental period was significantly shorter on full-grown larvae (18.87 days) as compared to 19.29 days on younger larvae.

❖ Optimum number of full grown *T. castaneum* larvae per larva of the predator was found to be 23.13 (19-24) with average total biomass of approximately 57.13mg and numbers less than this significantly reduced cocoon weight, while offering less than 10 larvae per predator larva besides reducing cocoon weight it reduced survival pre cent drastically.

❖ The optimum interval to offer the freeze killed prey, *T. castaneum* larvae for *M. boninensis* was found to be three days. Intervals longer than this significantly reduced the cocoon weight. Using three days interval the food need to be added 2-3 times during the developmental period of the predator larva.

❖ Refrigeration storage of *T. castaneum* larvae for more than two weeks, significantly reduced cocoon weight and prolonged developmental period, while storage beyond four weeks besides reducing cocoon weight and increasing developmental period, it also significantly reduced survival of the combine larval-cocoon stage.

❖ After eleven generations of continuous rearing of *M. boninensis* on factitious laboratory prey, *T. castaneum* larvae, the predator accepted original preys; the mustard aphid, *L. erysimi* and the mealy bug, *Phenacoccus solani* and completed its development on them successfully.

❖ The cost of producing 1cc of *C. cephalonica* eggs was Rs. 17.26, while the cost of producing 1g of *T. castaneum* larvae was Rs. 3.57. When *C. cephalonica* eggs were used as prey, the cost of producing 1,000 eggs of the predator was Rs. 15.91, while when *T. castaneum* larvae were used as prey, the cost of producing 1,000 eggs was Rs. 7.36.

ABSTRACT

The predator, green lacewing, *Mallada boninensis* (Okamoto) is an important bio-control agent used for suppression of a large number of insect pest species and mites in different crops and cropping systems. The present study was conducted to screen for a suitable laboratory host/prey, which can easily be produced with lesser effort, less hazardous, low cost, and can sustain the multiplication of the predator for many successive generations without deterioration of the progeny produced. Out of eight prey species and/or stages screened during one generation of *M. boninensis*; eggs of *Corcyra cephalonica* and larvae of *Tribolium castaneum* were found the most suitable for survival and development of immature stages leading to healthy progeny. *Tribolium castaneum* larvae were found more suitable than *C. cephalonica* eggs for survival and feeding by the predator, *M. boninensis* without any adverse effect on reproduction studied up to eleven generations (G). Biological attributes of the predator *viz;* survival of immature stages, longevity of male and female adults, oviposition period and fecundity were higher on *T. castaneum* larvae. Besides, pre-oviposition period was shorter and sex ratio favored dominance of females on *T. castaneum* larvae. Interestingly, predator's biological attributes like fecundity and longevity were getting better and better as generation advanced feeding on *T. castaneum.*

Fecundity of the predator was significantly higher (544.15 eggs/female) on *T. castaneum* larva as against lower (406.56 eggs/female) on *C. cephalonica* eggs. Fecundity on *T. castaneum* reached up to 876.75 eggs/female by end of G_{10}. Further, studies on the age-specific cohort life tables of *M. boninensis* on the two preys revealed the net reproductive rate (R_0), 139.12 and 171.43 females/female/generation; mean generation time (T), 33.83 and 34.78 days; intrinsic rate of natural increase (r_m), 0.1458789 and 0.1478956 females/female/day and the finite rate of increase (λ), 1.1571 and 1.1593 females/female/day on *C. cephalonica* and *T. castaneum*, respectively.

Optimum number of *T. castaneum* adults to produce maximum biomass (3.81±0.07g) of larvae/100g wheat flour was 140 beetles which produced 1545±29.67 larvae with average weight/larva of 2.47mg. Full-grown *T. castaneum* larvae as prey for *M. boninensis* resulted in significantly higher survival and significantly shorter developmental period of the predator than younger ones. Optimum feeding potential

of a predator larva on fully-grown *T. castaneum* was 23.13 (19-24) larvae equivalent to 57.13mg biomass.

The optimum interval to offer the freeze-killed prey, *T. castaneum* larva for *M. boninensis* was three days. Intervals longer than this significantly reduced the cocoon weight. Cold storage of *T. castaneum* larva for more than two weeks significantly reduced the cocoon weight and prolonged developmental period, while storage beyond four weeks reduced survival of the combine larval-cocoon stage.

The cost of producing 1,000 eggs of *M. boninensis* in the laboratory was Rs. 15.91 on *C. cephalonica* eggs as compared to Rs. 7.36 on *T. castaneum* larvae.

परभक्षी ग्रीन लेस विंग, *मेलाडा बोनीनेन्सिस* (ओकामोटो) (न्यूरोप्टेराः क्राइसौपिडी) के बडे पैमाने पर उत्पादन के लिए संभावित परपोषी की खोज

Title of thesis: " Exploration of potential host for mass production of green lacewing, *Mallada boninensis* (Okamoto) (Neuroptera: Chrysopidae)''

सारांश
ABSTRACT

परभक्षी ग्रीन लेसविंग, *मेलाडा बोनीनेन्सिस* (ओकामोटो) एक महत्वपूर्ण जैव–नियंत्रक कारक है, जो विभिन्न फसलों और फसल–प्रणालियों में लगने वाली अनेक नाशीकीट प्रजातियों और (माइट) चिचिडियों की रोकथाम के लिए प्रयोग किया जाता हैं। इस अध्ययन का उद्देश्य एक उपयुक्त परपोषी /भक्ष्य को ढूढना है जो प्रयोगशाला में कम लागत, कम प्रयास, एवं बिना जोखिम के आसानी से उत्पादित किया जा सके और जिसपे परभक्षियों की अनेक भावी पीढ्यिो की संतति बिना किसी विकार के पैदा होती रहे। इस श्आठ पोषक/शिकार प्रजातियों में से *कारसाइरा सिफेलोनिका* के अंडे और *ट्राइबोलियम कैस्टेनियम* के शिशु (लारवा) स्वस्थ संतति उत्पन्न करन हेतू उपयोगी पाए गए। परभक्षी द्वारा भक्षण किए जाने के संदर्भ में *ट्रा. कैस्टेनियम* के विकसित शिशु,*सी. सिफेलोनिका* की तुलना में अधिक उपयुक्त पाए गए। इस परीक्षण में *एम. बोनिनेन्सिस* का प्रजनन 11 पीढ़ियों (जी) तक अध्ययन किया गया। और पोषी का कोई भी प्रतिकूल प्रभाव इस परभक्षी पर नहीं देखा गया। *टी. कैस्टेनियम* के शिशुओं को परभक्षी को खिलाने पर परभक्षी की जीवविज्ञानी विशेषताओं जैसे अपरिपक्व अवस्थाओं ,नर और मादा वयस्कों की जीवनशीलता, अंडजनन अवधि और जनन क्षमता पर उच्च वृदि र्दज की गई। इसके अलावा पूर्व अंडजनन अवधि तथा लिंग अनुपात में मादाओं की प्रमुखता देखी गई। यह उल्लेखनीय है कि जनन क्षमता और जीवनशीलता जैसे इस परभक्षी के जीव विज्ञानी गुण, *टी. कैस्टेनियम* को खिलाने के उपरान्त पीढ़ी–दर–पीढ़ी बेहतर होते चले गए।

परभक्षी की प्रजनन क्षमता *सी. सिफेलोनिका* के अंडों पर कम (406.56 अंडा प्रति मादा) थी, जबकि *टी. कैस्टेनियम* के शिशुओं पर उच्च (544.15 अंडा प्रति मादा) थी। *टी. कैस्टेनियम* पर परभक्षी की प्रजनन क्षमता दसवीं पीढ़ी के अंत में 876.75 अंडा प्रति मादा पहुंच गई। *एम. बोनिनेन्सिस* पर दो शिकारों की आयु–विशिष्ट कोहॉर्ट जीवन

तालिकाओं के अध्ययन से यह स्पष्ट हुआ कि क्रमशः परभक्षी की *सी. सिफेलोनिका* और *टी. कैस्टेनियम* पर निवल प्रजनन दर (R_o)

139.12 और 171.43 मादाएं प्रति मादा प्रति पीढ़ी थी; औसत जनन समय (T) 33.83 और (इन्ट्रिन्सिक रेट) (rm) 0. 1458789 तथा 0.1478956 मादाएं प्रति मादा, प्रतिदिन और वृद्धि की निश्चित दर (¥) 1.1571 और 1.51593 मादाएं प्रति मादा प्रतिदिन थीं।

प्रति 100 ग्राम गेहूं के आटे में सर्वाधिक जीव द्रव्य उत्पन्न करने के लिए (3.84±0.07 ग्राम) *टी. कैस्टेनियम* के वयस्कों की इष्टतम संख्या 144 भृग थी जिससे 1.545±29.67 लारवा उत्पन्न हुए जिनका औसत भार प्रति लार्वा 2.47 मि. ग्रा. था। *एम. बोनिनेन्सिस* के शिकार के रूप में पूर्ण विकसित *टी. कैस्टेनियम* के लार्वी से उल्लेखनीय रूप से उच्च जीवनशीलता और शिशुओं की तुलना में परभक्षियों की अल्प विकास अवधि प्राप्त हुई। पूर्ण विकसित *टी. कैस्टेनियम* पर परभक्षी के लार्वी की इष्टतम भक्षण क्षमता 23.13 (19–24) लार्वे थी जो 57.13 मि.ग्रा. जीव द्रव्य के समतुल्य है।

एम.बोनिनेन्सिस के लिए *टी. कैस्टेनियम* के लार्वों को शीत घर में रखकर मारे जाने में लगने वाला उपयुक्त अन्तराल का समय तीन दिन था। इससे अधिक अन्तराल होने पर *एम.बोनिनेन्सिस* के कोकून के भार में उल्लेखनीय कमी पाई गई। *टी. कैस्टेनियम* के लार्वों को दो सप्ताह से अधिक अवधि तक शीत भंडार गृहों में रखने पर उनके कोकून भार में उल्लेखनीय कमी हुई और उनके विकास की अवधि लम्बी हो गई, जबकि चार सप्ताह से अधिक अवधि के भंडारण के दौरान लार्वा–कोकून अवस्था की जीवनशीलता में कमी आई।

सी. सिफेलोनिका के अंडों पर परभक्षी *एम. बोनिनेन्सिस* के एक हजार अंडों को उत्पन्न करने की लागत 15.91 रू0 थी। जबकि *टी. कैस्टेनियम* के लार्वों पर इतने ही अंडे उत्पन्न करने की लागत 7.36 रू0 मात्र आयी जो पहले की अपेक्षा लगभग आधी से कम है। अतः परभक्षी के वृहद उत्पादन हेतु *टी. कैस्टेनियम* के शिशुओं को पहली बार इस शोध द्वारा सस्ता, प्रभावकारी, एवं सुरक्षित पाया गया।

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Appendix I. Male longevity of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae for several generations

Corcyra eggs	Generations									
	G1	G2	G3	G4	G5	G6	G7	G8	G10	G11
R1	52	48	43	38	56	41	27	31	49	54
R2	66	50	48	60	27	45	39	30	48	14
R3	40	14	48	61	30	43	49	27	33	30
R4	38	36	33	27	48	61	54	25	36	37
R5	27	49	47	14	50	17	44	32	36	6
R6	45	53	50	22	33	30	39	54	29	28
R7	45	11	45	25	10	14	31	50	32	39
R8	10	38	34	22	31	40	43	40	38	29
R9	40	17	47	19	29	24	35	50	32	68
R10	19	32	51	24	38	33	56	9	26	96
R11	26	9	45	58	17	16	47	45	35	76
R12	26	19	36	51	40	27	35	43	22	72
Mean	**36.17**	**31.33**	**43.92**	**35.08**	**34.08**	**32.58**	**41.58**	**36.33**	**34.67**	**45.75**
***Tribolium* larvae**										
R1	39	58	45	39	60	45	48	44	85	81
R2	43	53	18	39	59	43	58	46	101	70
R3	31	39	15	45	35	38	47	38	98	52
R4	41	43	44	41	28	26	46	41	66	62
R5	40	47	43	38	36	51	56	68	75	68
R6	42	44	43	45	38	50	59	58	107	67
R7	44	47	9	34	21	40	40	67	87	56
R8	21	35	37	18	31	20	41	38	98	71
R9	14	36	13	30	52	24	46	29	88	50
R10	26	49	42	40	25	33	40	50	88	76
R11	33	49	32	33	33	42	42	33	67	66
R12	15	41	23	31	13	37	41	52	56	53
Mean	**22.43**	**45.08**	**30.33**	**36.08**	**35.92**	**37.42**	**47.00**	**47.00**	**84.67**	**64.33**

Appendix II. Female longevity of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae for several generations

Corcyra eggs	Generations									
	G1	G2	G3	G4	G5	G6	G7	G8	G10	G11
R1	53	42	52	39	58	50	51	56	57	44
R2	71	54	58	61	55	40	39	29	50	14
R3	62	17	37	48	49	28	48	52	39	20
R4	17	41	36	30	34	56	43	39	46	46
R5	52	57	50	47	46	26	47	42	33	52
R6	46	59	42	48	47	51	52	56	20	74
R7	44	30	60	51	25	44	31	50	34	104
R8	66	47	34	41	38	61	49	38	24	25
R9	66	29	53	39	42	54	34	58	58	92
R10	37	56	61	54	41	20	47	27	41	55
R11	44	24	49	28	41	42	35	48	25	43
R12	55	55	42	57	37	56	38	47	40	30
Mean	**51.08**	**42.58**	**47.83**	**45.25**	**42.75**	**44**	**42.83**	**45.17**	**38.92**	**49.92**
***Tribolium* larvae**										
R1	40	57	51	46	39	53	43	33	77	59
R2	55	55	46	54	54	39	48	56	93	60
R3	69	47	37	44	63	30	61	59	106	81
R4	52	55	43	43	30	29	47	55	94	52
R5	39	52	41	34	36	51	46	38	64	83
R6	38	63	47	40	52	51	47	54	65	80
R7	42	51	44	39	25	47	18	58	57	71
R8	32	52	63	46	58	38	53	52	46	74
R9	53	37	18	33	63	53	41	48	22	81
R10	58	40	45	41	46	50	41	52	88	77
R11	35	52	55	32	54	46	28	50	60	67
R12	45	32	36	23	25	38	43	51	56	75
Mean	**46.50**	**49.42**	**43.83**	**39.58**	**45.42**	**43.75**	**43.00**	**48.38**	**69.00**	**71.75**

Appendix III. Total fecundity of *M. boninensis* reared on *C. cephalonica* eggs and *T. castaneum* larvae for several generations

Corcyra eggs	Generations									
	G1	G2	G3	G4	G5	G6	G7	G8	G10	G11
R1	718	227	502	506	568	355	434	479	407	326
R2	842	448	391	438	979	323	406	72	266	50
R3	923	121	470	383	455	137	318	572	339	199
R4	61	185	469	452	354	394	360	335	320	590
R5	558	586	403	621	644	215	410	473	222	539
R6	305	617	346	704	402	384	428	461	217	582
R7	342	312	354	359	156	305	318	578	253	695
R8	845	439	273	513	805	398	416	332	245	294
R9	861	283	466	343	313	329	293	397	312	770
R10	367	519	853	294	326	90	274	159	271	407
R11	546	88	724	298	196	258	341	374	103	81
R12	586	538	450	544	464	634	353	409	259	91
Mean	**579.5**	**363.58**	**475.08**	**454.58**	**471.83**	**318.5**	**362.58**	**386.75**	**267.833**	**385.33**
***Tribolium* larvae**										
R1	668	607	560	682	162	523	454	83	861	703
R2	534	425	498	643	699	236	508	523	794	520
R3	1245	413	492	460	555	397	462	554	1096	910
R4	528	710	478	600	294	104	468	549	1067	588
R5	592	576	360	586	278	468	516	209	839	1113
R6	505	574	454	379	406	512	484	577	725	757
R7	445	525	433	721	325	570	203	590	675	871
R8	312	443	921	520	553	342	459	599	697	954
R9	574	190	139	149	639	523	353	365	324	1035
R10	526	725	422	382	414	489	404	459	1810	780
R11	716	421	700	286	571	243	274	520	702	771
R12	768	293	275	249	336	415	352	486	931	566
Mean	**617.75**	**491.83**	**477.67**	**471.42**	**436**	**401.83**	**411.42**	**459.5**	**876.75**	**797.33**

Appendix IV. Cost of production of the prey, *Corcyra cephalonica* eggs

Equipment

S. No.	Particulars	Unit	Price/unit (Rs)	Total (Rs.)
1.	Steel racks	10	3,600.00	36,000.00
2.	Rearing jars	200	40.00	8,000.00
3.	Enamel trays	4	160.00	640.00
4.	Oviposition cages	15	50.00	750.00
5.	Hot air oven	1	900.00	900.00
6.	UV-chamber	1	880.00	880.00
7.	Refrigerator	1	8200.00	8200.00
8.	Scissors	4	25.00	100.00
9.	Camel hair brush	8	3.00	24.00
	Total			**55,494.00**

Working capital

S. No.	Particulars	Unit	Price/unit (Rs)	Total (Rs.)
1.	Sorghum/maize grains	1000 kg	12.00	12,000.00
2.	Milling charge	-	1.00	1,000.00
3.	Yeast	2.2 kg	360.00	792.00
4.	Markin cloth	30 m	25.00	750.00
5.	Rubber bands	4k g	30.00	1,200.00
6.	Labour charge	2/day (365)	120.00	87,600.00
7.	Water & electricity charge	12 months	1200.00	14,400.00
	Total			**117,742.00**

Total fixed cost (TFC)

Depreciation on equipment			
Depreciation/year = 13%	=	Rs.	7,214.22
Interest on fixed cost (@18%)	=	Rs.	9,988.92
Annual rent	=	Rs	40,000.00
Total fixed cost/ year	=	**Rs**	**57,203.14**

Total Variable cost (TVC)

Working capital	=	Rs	117,742.00
16% interest on working capital	=	Rs.	18,838.72
Total Variable Cost/year	=	**Rs.**	**136,580.72**
Total Cost (TFC + TVC)	=	**Rs.**	**193,783.86**
Amount of eggs produced/kg of grains (cc)	=	11.23	
Total amount of eggs obtained (cc)/year	=	11,230	
Cost of production/cc (Total cost /cc of eggs obtained)	=	Rs. 17.26	

Appendix V. Cost of production of the prey, *Tribolium castaneum* larvae

Equipments

S. No.	Particulars	Unit	Price/unit (Rs)	Total (Rs.)
1.	Steel racks	10	3,600.00	36,000.00
2.	Rearing jars	60	40.00	2,400.00
3.	Trays	10	160.00	1,600.00
4.	Hot air oven	1	900.00	900.00
5.	Refrigerator	1	8200.00	8200.00
6.	Scissors	4	25.00	100.00
7.	Camel hair brush	8	3.00	24.00
	Total			**49,224.00**

Working capital

S. No.	Particulars	Unit	Price/unit (Rs)	Total (Rs.)
1.	Wheat flour	1000 kg	13	13,000.00
2.	Markin cloth	30m	25.00	750.00
3.	Rubber bands	4 kg	30.00	1,200.00
4.	Labour charge	1/day (365)	120.00	43,800.00
5.	Water & electricity charge	12 months	1200.00	14,400.00
	Total			**73,150.00**

Total fixed cost (TFC)

Depreciation/year = 13%	=	Rs	6,399.12
Interest on fixed cost (@18%)	=	Rs	8,860.32
Annual rent	=	Rs.	40,000.00
Total fixed cost/ year	=	**Rs.**	**51,259.44**

Total Variable cost (TVC)

Working capital	=	Rs	73,150.00
Interest on working capital (16%)	=	Rs	11,704.0
Total Variable Cost/ year	=	Rs.	84,854.00
Total (TFC + TVC)	=	Rs.	136,113.44
Amount of larvae obtained/kg flour	=	38.10 g	
Total amount of larvae obtained/year	=	38100.00 g	
Cost of production/g (Total cost/g of larvae obtained)	=	Rs. 3.57	

Appendix VI. Cost of production of *Mallada boninensis* on *Corcyra cephalonica* eggs

Equipments

S. No.	Particulars	Unit	Price/unit (Rs)	Total (Rs.)
1.	Steel racks	10	3,600.00	36,000.00
2.	Plastic trays	80	45.00	3,600.00
3.	Glass vials	17,000	1.50	25,000.00
4.	Adult rearing jars	150	45.00	6,750.00
5.	Plastic dibbies	280	1.00	280.00
6.	Scissors and forceps	3 each	35.00	105.00
7.	Camel hair brush	10	2.50	25.00
	Total			**71,760.00**

Working capital

S. No.	Particulars	Unit	Price/unit (Rs)	Total (Rs.)
1.	Honey	14	320.00	4,480.00
2.	Absorbent cotton	30	40.00	1,200.00
3.	*Corcyra* eggs to feed 150,000 larvae	7,500 cc	17.26	129,419.31
4.	Markin cloth	40 m	25.00	1,000.00
5.	Rubber bands	4 kg	30.00	1,200.00
6.	Labour charge	2/day (365)	120.00	87,600.00
7.	Water and electricity charge	12 months	1200.00	14,400.00
	Total			**239,299.31**

Total fixed cost (TFC)

Depreciation on equipment			
Depreciation/ year = 13%	=	Rs	9,328.80
Interest on fixed cost (@18%)	=	Rs.	12,916.80
Annual rent	=	Rs.	40,000.00
Total fixed cost/ year	=	**Rs.**	**62,245.60**

Total Variable cost (TVC)

Working capital	=	Rs.	239,299.31
16% interest on working capital	=	Rs.	38,287.89
Total Variable Cost/ year	=	**Rs.**	**277,587.20**
Total Cost (TFC + TVC)	=	**Rs.**	**339,832.80**

No. of adults produced = 150,000 x 70% = 105,000

No. of female adults = 105,000/2 = 52,500

Total number of eggs obtained (in 1000)/year = 52,500 x 407 = 21,367.5

Cost of production of 1000 eggs (Total cost/eggs obtained in 1000) = **Rs. 15.91**

Appendix VII. Cost of production of *Mallada boninensis* on *Tribolium castaneum* larvae

Cost of equipments = Rs. 71,760.00

Working capital

S. No.	Particulars	Unit	Price/unit (Rs)	Total (Rs.)
1.	Honey	14	320.00	4,480.00
2.	Absorbent cotton	30	40.00	1,200.00
3.	*T. castaneum* larvae (to feed 150,000 larvae)	8,550 g	3.57	30,523.5
4.	Markin cloth	40 m	25.00	1,000.00
5.	Rubber band	4 kg	30.00	1,200.00
6.	Labour charge	2/day (365)	120.00	87,600.00
7.	Water & electricity charge	12 months	1200.00	14,400.00
	Total			**140,403.50**

Total fixed cost = Rs. 62,245.60

Total Variable cost (TVC)

Working capital	=	Rs.	140,403.50
16% interest on working capital	=	Rs.	22,464.56
Total Variable Cost/ year	=	**Rs.**	**162,868.06**
Total Cost (TFC + TVC)	=	**Rs.**	**225,113.66**

No. of adults produced = 150,000 x 75% = 112500
No. of female adults = 112500/2 = 56250
Total number of eggs obtained (in 1000)/year = 56250 x 544 = 30,600
Cost of production of 1000 eggs (Total cost of eggs obtained in 1000) = **Rs 7.36**