Mass multiplication, large scale release and biocontrol potential evaluation of a reduviid predator *Rhynocoris longifrons* (Stål) (Insecta: Heteroptera: Reduviidae) against chosen agricultural insect pests

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By

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Declaration

I hereby declare that the thesis entitled "**Mass multiplication, large scale release and biocontrol potential evaluation of a reduviid predator *Rhynocoris longifrons* (Stål) (Insecta: Heteroptera: Reduviidae) against chosen agricultural insect pests**" submitted by me for the Degree of Doctor of Philosophy in Zoology is the result of my original and independent research work carried out under the guidance of Dr. Dunston P. Ambrose, D.Sc., Director, Entomology Research Unit, St. Xavier's College (Autonomous), Palayamkottai – 627 002 and it has not been submitted for the award of any degree, diploma, associateship, fellowship of any University or Institution.

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Place: Palayamkottai

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Abstract

Arthropod predators are important in the Integrated Pest Management (IPM) of cotton insect pests. Entomologists now concentrate more on the biocontrol of insect pests by using predators and parasitoids. Studying the predatory insects in the agroecosystems is a rewarding exercise in the context of identifying the natural predators to combat the insect pests affecting the cultivated crops. Hemipteran predators are important biocontrol agents of many agricultural and forests pests. Among them, the family Reduviidae is the least researched and most poorly understood one, although evidence in support of their potential in biocontrol is accumulating. Reduviid predators are very often reported as predators of various insect pests of many crops of agricultural and horticultural plantations as well as forest vegetations. They are present in the scrub jungles, semiarid zones and tropical rainforests bordering the agroecosystems and are found to be predating upon a wide variety of insect pests found in the agroecosystems. The present investigation carried out in the Entomology Research Unit (ERU) for the past four years deals with biocontrol aspects such as prey preference, stage preference, functional and numerical responses, chemical ecology, field cage evaluation, augmentative release and field colonization of a reduviid *Rhynocoris longifrons* (Stål) against chosen agricultural insect pests.

Among different pests the fourth nymphal instars of *R. longifrons* preferred *S. litura* (76.58 %) to *D. cingulatus* (20.13 %) and *M. indica* (3.30 %). The fifth nymphal instars of *R. longifrons* preferred *S. litura* (72.88 %) to *D. cingulatus* (22.28 %) and *M. indica* (4.83 %). The adult males of *R. longifrons* preferred *S. litura* (72.00 %) to *D. cingulatus* (21.07 %) and *M. indica* (6.92 %). The adult females of *R. longifrons* preferred *S. litura* (70.69 %) to *D. cingulatus* (20.40 %) and *M. indica* (8.91 %). Among

lepidopteran pests the life stages of *R. longifrons* preferred *S. litura*. The fourth nymphal instars of *R. longifrons* preferred *S. litura* (53.33 %) to *H. armigera* (20.61 %), *E. mollifera* (14.55 %) and *A. janata* (11.52 %). The fifth nymphal instars of *R. longifrons* preferred *S. litura* (53.29 %) to *H. armigera* (20.58 %), *E. mollifera* (13.17 %) and *A. janata* (12.96 %). The adult males of *R. longifrons* preferred *S. litura* (44.70 %) to *H. armigera* (23.10 %), *E. mollifera* (16.10%) and *A. janata* (16.10 %). The adult females of *R. longifrons* preferred *S. litura* (52.47 %) to *H. armigera* (21.18 %), *E. mollifera* (14.19 %) and *A. janata* (12.16%).

The different life stages of *R. longifrons* preferred the different size groups of *S. litura* larvae. The first nymphal instars preferred the *S. litura* larval size groups ranging from 0.1 to 2.0 cm long (66.07 %). The second nymphal instars also highly preferred the *S. litura* larval size groups ranging from 0.1 to 2.0 cm long though they accepted 2.1 to 3.0 cm long prey. The third nymphal instars accepted the *S. litura* larval size groups ranging from 0.1 to 4.0 cm long, but they highly preferred 0.1 to 3.0 cm long larvae. The fourth and fifth nymphal instars and adult males and females of *R. longifrons* accepted the prey size groups ranging from 1.0 to 5.0 cm long, but they highly preferred the larger size groups i.e., 3.to 5.0 cm long.

As observed for *S. litura* the different life stages of *R. longifrons* preferred the different size groups of *H. armigera* larvae. The first nymphal instars preferred the *H. armigera* larval size groups ranging from 0.1 to 2.0 cm long. The second nymphal instars highly preferred the *H. armigera* larvae ranging from 1.0 to 2.0 cm long though they accepted the size groups ranging from 0.1 to 3.0 cm long. The third and fourth nymphal instars preferred the *H. armigera* larval size groups ranging from 0.1 to 4.0 cm long. Though the fifth nymphal instars and adult females of *R. longifrons* accepted the different larval size groups of *H. armigera* ranging from 2.0 to 5.0 cm long, they highly preferred the larger size groups i.e., size ranging from 3.0 to 5.0 cm long size preys. The adult males of *R. longifrons* highly preferred the prey size groups ranging 3.0 to 5.0 cm long though the accepted prey size groups ranging from 0.1 to 5.0 cm long by them.

The different life stages of *R. longifrons* preferred different life stages of *D. cingulatus*. The first nymphal instars of *R. longifrons* highly preferred the first nymphal instars of *D. cingulatus* (52.57 %) though they accepted second and third nymphal instars. Although the second nymphal instars of *R. longifrons* accepted the first, second, third and fourth nymphal instars of *D. cingulatus*, they highly preferred the second nymphal instars of *D. cingulatus* (40.57 %). The third nymphal instars of *R. longifrons* accepted all the nymphal stages of *D. cingulatus* but they highly preferred the third and fourth nymphal instars (40.13 % and 35.03 % respectively). The fourth nymphal instars of *R. longifrons* highly preferred the fourth and fifth nymphal isntars of *D. cingulatus* than the other stages such as second and third nymphal instars and adults. Though the fifth nymphal instars and adult males and females of *R. longifrons* accepted the third, fourth and fifth nymphal instars and adults of *D. cingulatus* they highly preferred the fifth nymphal instars.

The functional responses of IV and V nymphal instars and adult males and females of *R. longifrons* were studied in the cotton branch cages. They responded to increasing prey density of two lepidopteran insect pests such as *S. litura* and *H. armigera* and a hemipteran pest *D. cingulatus* by killing more number of preys than prey killed at lower prey densities. Thus, they exhibited curvilinear type II functional response. Most predators consumed all or most of the prey provided at lower prey densities and showed a deceleration in rate of predation with greater variation at higher prey densities. This was further confirmed by the positive correlation obtained between the prey density and the prey killed [(a) $y = 0.139 + 0.496x$; $r = 0.999$, $y = 0.146 + 0.547x$; $r = 0.998$, $y = -0.054 +$

$0.610x$; $r = 0.998$ and $y = 0.053 + 0.626x$; $r = 0.999$, (b) $y = 0.605 - 0.38x$; $r = 0.955$, $y = 0.536 + 0.412x$; $r = 0.972$, $y = 0.268 + 0.478x$; $r = 0.985$ and $0.126 + 0.505x$; $r = 0.984$ and (c) $y = 0.425 + 0.391x$; $r = 0.994$, $y = 0.421 + 0.417x$; $r = 0.996$, $y = 0.381 + 0.443x$; $r = 0.998$ and $y = 0.59 + 0.43x$; $r = 0.993$ for the IV and V nymphal instars and adult males and females of the predators to (a) *S. litura* larvae, (b) *H. armigera* larvae and (c) *D. cingulatus* adults respectively)].

The maximum predation was represented by 'k' value. It was always found restricted to the higher prey density ($k = 8.028$, 8.944, 9.861 and 10.083 for the IV and V nymphal instars and adult male and female predators of *S. litura* larvae, $k = 6.139$, 6.667, 7.528 and 7.806 for the IV and V nymphal instars and adult male and female predators of *H. armigera* larvae and $k = 6.528$, 6.973, 7.389 and 7.25 for the IV and V nymphal instars and adult male and female predators of *D. cingulatus* adults respectively).

The searching time decreased as the prey density increased. Uniformly negative correlations were obtained between the prey densities and the searching times of the predator at all prey densities [(a) $y = 5.897 - 0.371x$; $r = -0.999$, $y = 5.902 - 0.36x$; $r = -0.998$, $y = 6.032 - 0.37x$; $r = -0.998$ and $y = 5.968 - 0.372x$; $r = -0.999$, (b) $y = 5.408 - 0.372x$; $r = -0.955$, $y = 5.516 - 0.371x$; $r = -0.972$, $y = 5.786 - 0.381x$; $r = -0.985$ and $y = 5.903 - 0.388x$; $r = -0.984$ and (c) $y = 5.608 - 0.36x$; $r = -0.994$, $y = 5.637 - 0.359x$; $r = -0.996$, $y = 5.69 - 0.36x$; $r = -0.998$ and $y = 5.551 - 0.356x$; $r = -0.993$ for the IV and V nymphal instars and adult males and females of the predators to (a) *S. litura* larvae, (b) *H. armigera* larvae and (c) *D. cingulatus* adults respectively)].

Numerical responses of *R. longifrons* to different densities of rice meal moth *Corcyra cephalonica* Stainton and *S. litura* was studied under laboratory conditions. *R. longifrons* reared at10, 20, 30 and 40 prey densities showed 56.67, 66.67, 71.67 and 76.67 per cent survival respectively on larvae of *C. cephalonica* and 58.33, 61.67, 73.33 and

78.33 on larvae of *S. litura*. There was a positive relationship between the per cent survival of *R. longifrons* and the prey density. The IV and V nymphal stadia of *R. longifrons* were 15.08 and 18.76, 13.89 and 17.04, 12.62 and 15.51 and 11.35 and 13.87 days at 10, 20, 30 and 40 prey densities respectively on *C. cephalonica* and 13.57 and 17.87, 12.38 and 16.86, 11.90 and 14.29 and 11.23 and 13.67 days at 10, 20, 30 and 40 prey densities respectively on *S. litura*. The adult longevities of *R. longifrons* were 96.67, 92.73, 90.09 and 89.91 days at 10, 20, 30 and 40 prey densities respectively on larvae of *C. cephalonica* and 92.40, 89.62, 87.14 and 85.17 days at 10, 20, 30 and 40 prey densities respectively on larvae of *S. litura*. The preoviposition periods of *R. longifrons* were 12.47, 11.95, 11.13 and 10.52 days at 10, 20, 30 and 40 prey densities respectively on larvae of *C. cephalonica* and 12.33, 12.05, 11.20 and 10.31 days at 10, 20, 30 and 40 prey densities respectively on larvae of *S. litura*. The fecundity of *R. longifrons* were 85.53, 88.19, 90.48 and 91.56 at 10, 20, 30 and 40 prey densities respectively on larvae of *C. cephalonica* and 86.06, 88.50, 90.08 and 92.19 at 10, 20, 30 and 40 prey densities respectively on larvae of *S. litura*. The hatchability of *R. longifrons* were 89.64, 91.99, 93.09 and 93.51 at 10, 20, 30 and 40 prey densities respectively on larvae of *C. cephalonica* and 90.80, 91.70, 92.13 and 92.81 at 10, 20, 30 and 40 prey densities respectively on larvae of *S. litura*.

The total distance travelled was indirectly proportional to the prey deprivation level i.e., the total distance travelled by *R. longifrons* decreased with increased prey deprivation days. For instance, the distance travelled was 185.50±13.89, 151.17±9.06 and 114.67±9.09 cm in 1, 2 and 4 days prey deprived predator respectively. The total distance travelled by *R. longifrons* was also decreased with increased prey density. The distance travelled was 182.17±7.83, 154.17±8.75 and 84.17±7.39 cm at 1, 2 and 4 days prey densities respectively. Prey deprivation also significantly influenced the predator's searching speed. In 4 day prey deprived *R. longifrons*, the highest rate of searching speed of 7.83±0.75 cm/10s was observed whereas it was 9.00±1.26 cm/10s and 7.83±0.75 cm/10s at 2 and 1 day prey deprived categories respectively. Predator's searching speed also increased as prey density increased. The highest rate of searching speed of 12.16±1.16 cm/10s was observed at 4 prey density followed by 8.83±1.47 cm/10s and 6.67±0.82 cm/10s at 2 and 1 prey densities respectively. The turning rate was found directly proportional to the prey deprivation and prey densities, i.e., the turning rate increased as duration of the prey deprivation and prey density increased. The turning rate was 3.33±1.21, 5.83±0.75 and 7.00±1.41 (cm) in 1, 2 and 4 days prey deprived predators respectively and 4.50±1.05, 9.17±1.47 and 9.50±1.05 (cm) at 1, 2 and 4 prey densities respectively. The turning angle was also directly proportional to the prey deprivation and prey densities, i.e., the turning angle increased as the prey deprivation and prey density increased. The turning angle was 6.67±1.21, 10.17±1.72 and 11.16±1.47 (cm) at 1, 2 and 4 days prey deprived predators respectively and 8.33±0.87, 13.17±1.47 and 17.83±2.32 (cm) at 1, 2 and 4 prey densities respectively.

The biology and life table parameters of *R. longifrons* on *S. litura* were carried out in the laboratory. The incubation period of *R. longifrons* was 8.63±1.83 days. The longevity of male (58.95±12.55 days) was shorter than that of females (69.49±13.99 days). The preoviposition period, index of oviposition period and postoviposition period were 6.20±0.98 days, 18.95±2.88 and 6.2±5.05 days. The average number of eggs per female was 115.55. The net reproductivity rate (R_0) was 115.01. The innate capacity of natural increase (r_m) of the predator was 0.04. The true intrinsic rate of increase (r_m) was 0.0426. The population was able to multiply 1.347 times every week and it doubled every 16.096. The hypothetical population in F_2 generation of *R. longifrons* was 13227.3 in a generation time of 129.89 days with a daily finite rate increase (λ) of 1.044.

The survival rate was found directly proportional to the prey density i.e., as the prey density increased the survival rate also increased. The per cent survival rates of *R. longifrons* were 53.33±8.61, 63.34±5.09 and 81.11±8.96 at 10, 20 and 30 prey densities respectively. Unlike prey density, crowding was indirectly proportional to per cent survival rate i.e., as the predator density increased the survival rate decreased. The maximum survival rate of 86.67±7.45 was observed at 10 predator density followed by 73.33±5.53 and 44.45±15.71 at 20 and 30 predator densities respectively. Feeding interval also affected the survival rate of *R. longifrons*. Like predator density, the per cent survival also decreased with increased feeding interval. The per cent survival rate of *R. longifrons* was 80.00±7.07, 67.50±6.89 and 56.67±6.06 at 0, 1 and 2 days intervals respectively. Substrates also influenced the survival rate of *R. longifrons*. The highest survival rate of 85.00±8.16 was observed in substrate of sand with stone followed by 69.12±6.72 in substrate of cotton plant shoot with leaves and the least survival rate of 50.00±6.45 was observed in the untreated plastic containers.

The bioassay experiments performed only in the Y-shaped olfactometer and time spend by the predators *R. longifrons* to the hexane extracts of insect pests suggested behavioural responses of predators. When the predator *R. longifrons* was released into the main chamber of the Y-shaped olfactometer, it oriented towards the odour source present in the sterile cotton with antennae directing towards the odour source. After getting perfect orientation it palpated the antennae, followed by rubbing legs, rostral cleaning and extending towards the odour source. Once the predator entered the sample cell it quickly approached the odour cell with extended rostrum. The positive approaching responses were exhibited by *R. longifrons* to the hexane fractions of all the insect pests. The highest response of 6.67±1.18 min. was observed to *S. litura* which is followed by 5.17±0.89, 4.42±1.04, 3.00±0.82 and 2.42±0.76 min. for *H. armigera*, *A. janata*, *M. indica* and *D.*

cingulatus respectively. The predator *R. longifrons* exhibited the highest handling time to *S. litura* extract (6.33±1.25 min.) followed by *H. armigera* (5.58±1.11min.), *A. janata* (2.92±0.76 min.), *M. indica* (2.50±0.65 min) and *D. cingulatus* (1.75±0.72 min.). The Excess Proportion Index values (EPI) of *R. longifrons* showed positive response to the *S. litura* (0.67), *H. armigera* (0.33) and *A. janata* (0.17) larval extracts and negative responses to *M. pustulata* (-0.33) and *D. cingulatus* (-0.17). *R. longifrons* highly preferred the body extract of *S. litura* (41.67 %) followed by *H. armigera* (25.00 %) and *A. janata* (16.67 %) and the least preference were observed to the body extracts of *M. indica* (8.33 %) and *D. cingulatus* (8.33 %).

Rhynocoris longifrons significantly ($P<0.05$) suppressed the plant damage in *S. litura* infested cages and also minimized the damage in *D. cingulatus* and *M. indica* infested cages. For instance, 89 days after sowing the damage caused by *S. litura* was 3.33 in control and 2.53 in test plot. Similar trend were observed for *D. cingulatus* and *M. indica*. Yield significantly increased in plots infested with *S. litura, D. cingulatus* and *M. indica* with predators than in control plots without predators. The yield increased from 321.67 gm to 500.83 gm in *S. litura*; 328.17 gm to 489.33 gm in *D. cingulatus* and 284.17 gm to 307.83 in *M. indica* infested cages.

Attempts were made to augment *R. longifrons* in open cotton field against *S. litura* and *H. armigera*. The subsequent release of IV nymphal instars on 17th May 2009, V nymphal instars on 24th May 2009 and 14th June 2009, eggs (ready to hatch on next day) and adults on 31st May 2009 and III nymphal instars on 07th June 2009 significantly ($P<0.05$) affected the population of *S. litura* and *H. armigera*, but the effect was not significant with the release of eggs and adults. *R. longifrons* significantly ($P<0.05$) reduced the percentage of plant damage caused by the population of *S. litura* and *H. armigera* in test plots. The augmentation of *R. longifrons* did not influence the number of predatory arthropods. But the yield of seed cotton was not significantly greater in predator released plots (173.40 gm) than in control plots (158.20 gm).

An attempt was made to evaluate the effect of mulching practices with different mulches such as palmyra leaf, banana leaf, coconut spathe and stones on field colonization and biocontrol potential of *R. longifrons* in the cotton field at Muthukrishnaperi, Tirunelveli District, Tamil Nadu, South India. The percentage of good quality cotton was greater in palmyra leaves mulched plots (3530 kg/hec.) followed by coconut spathe plots (3430 kg/hec.), banana leaf plots (3378 kg/hec.) and stone laid plots (3280 kg /hec) than in control plots (2925 kg/hec.).

Chapter - I: Host Preference

Introduction

Preference of an insect population from specific resources is generally considered to result from the natural selection process maximizing population development (Esterbrook and Dunham, 1976). Moreover, diet specialization is a fundamental aspect of an animal's biology and has at the same time far reaching ecological implications. It is helpful to properly value the ecological impact of food behaviour and its evolutionary significance, if not a dire necessity, one should understand the underlying mechanisms of the behaviour (Schoonhoven and van Loon, 2002).

Generalist predators encounter several preys with different nutritional value and defensive mechanisms and the predator must develop several attack strategies to exploit a variety of preys. Optimal foraging theory predicts that the diet choice of a predator must maximize net nutrient gain and minimize energetic costs and predation risks (Stephen and Krebs, 1986). Generalist arthropod predators feed on varied prey species belonging to different families or even orders, among which they show no clear preference (Hsiao, 1985). A predator is classified as truly generalist when its prey selection is proportional to the relative abundance of the prey species in its environment (Begon *et al.*, 1996). However, some predators show some preference, i.e., they preferentially selects a prey over others, whatever the relative abundance of that prey (Cock, 1978; Hassell and Southwood, 1978). Most predaceous Heteroptera are governed in their choice of prey principally by its availability and size rather than its taxonomic affinity (Dolling, 1991). Although reduviids are polyphagous predators, they exhibit a narrow range of host preference (Ambrose, 1996, 1999, 2000a, 2003; Ambrose and Claver, 2001). Food

Chapter - II: Stage preference

Introduction

Hemipteran predators are important biocontrol agents of many agricultural insect pests (Biever and Chauvin, 1992; Clouteir and Bauduin, 1995; Ambrose, 1999, 2002; Grundy and Maelzer, 2000a). Of this group, reduviids are one of the least researched and most poorly understood families, although evidence in support of their potential in biocontrol is accumulating (Schaefer and Ahmad, 1987; James, 1994; Ambrose, 1999, 2002; Grundy and Maelzer, 2000a).

Eventhough a predator prefers the particular prey species it exhibits specific selection to a particular stage of the prey. Selection on one stage over another could also affect the dynamics of predator-prey interactions (Ambrose, 1996, 1999, 2003; Claver and Ambrose, 2002b). Prey size is a key element in the selection decisions of predators (Fantinou *et al.*, 2009). Prey size could influence prey selection. In some case, a larger prey item could supply higher nutrients but attack and capture could be more expensive and risky. Therefore, natural selection should have favoured a trade-off (Allan *et al.*, 1987; Molles and Pietruszka, 1987: Roger *et al.*, 2000).

Although reduviids are polyphagous predators, they certainly exhibit a certain degree of host specificity and also prefer a particular stage of the prey (Ambrose, 2000a). Moreover, host specificity of reduviid predators are governed principally by the size of their prey rather than their taxonomic affinity (Dolling, 1991; Schaefer, 1996). Moreover, the assessment of a predator's ability to capture and consume the relevant stadia of the targeted pest insect enables one to effectively utilize a natural enemy for biocontrol (Grundy and Maelzer, 2000a). Such information is essential for better utilization of any

Chapter - III: Functional Response

Introduction

The understanding of predator-prey interactions has been the purpose of numerous studies, especially those related to predator use in biological control in agroecosystems. Predation is assumed to be one of the significant biotic mortality factors reducing insect pest populations, and using them in insect pest management programmes has been receiving increased attention because of the current need to reduce the exclusive use of insecticides for pest control (DeBach and Rosen, 1991; Riudavents and Castane, 1998; Sarmento *et al.*, 2007). Functional response of a predator is one of the important key factors regulating population dynamics of predator–prey systems (Mandour *et al.*, 2006), and functional response curves can be used to infer basic mechanisms underlying predator–prey interactions, clarify coevolutionary relationships and enhance biological control (Houck and Strauss, 1985).

One of the fundamental aspects of a predator–prey interaction is the relationship between prey density and predator consumption, to which Solomon (1949) attributed the term "functional response". According to Holling (1959a & b, 1961), there are four basic types of functional response which include type I (linear), type II (curvilinear), type III (sigmoidal) and type IV (dome-shaped); governed by components such as exposure time, prey searching time, instant discovery rate or attack rate, prey searching efficiency and prey handling time (Holling, 1965; Hassel *et al.*, 1976). The responses of types I and II are found in most invertebrates, whereas type III is more common in vertebrates, although some arthropods can also show this response when their preferential prey is not available (Hassel *et a*l., 1977; Kidd and Jervis, 1996). Type IV response occurs only when other prey of the same or of a different species interferes in predator handling or if the prey

Chapter – IV: Numerical response

Introduction

The numerical response is defined as the change in the predator's reproductive output at varying prey densities (Sohrabi and Shishehbor, 2007). Since Solomon's (1949) original definition, two types of numerical responses have been defined and used to help elaborate the broad interactive dynamics between consumer populations and their food. These are: (i) a 'demographic' numerical response that links rate of change in consumer abundance to food availability (Caughley, 1976; May, 1981) and (ii) an 'isocline' numerical response that links consumer abundance *per se* to food availability (Holling, 1965, 1966 for total predator responses).

Predatory arthropods often have catholic feeding habits and long generation times relative to herbivores, so that even if there is a numerical response to changes in the density of a single herbivore species (Symondson *et al.*, 2002), the response is unlikely to occur quickly enough to lead to outbreak suppression (Hassell and May, 1986, DeBach and Rosen, 1991). Functional response probably affects the numerical response of invertebrate predators, which in turn influences the death rate of prey and the potential ability of the predator to suppress and stabilize prey population (Huffaker *et al.*, 1971; Takafuji and Chant, 1976). Numerical response may be caused by enhanced fecundity, aggregation (immigration into patches where hosts are more abundant) and improved survival (Huffaker *et al.*, 1971). Adult longevity and fecundity per female over life time was recorded for different prey density categories as an index of numerical response (Hagen, 1987).

Chapter - V: Searching behaviour

Introduction

Locating a food resource is probably one of the most important behaviours a mobile animal can undertake (O'Brien *et al.*, 1990). Searching behavior is an important activity in the life of predators and parasitoids. Bell (1990) defined searching behaviour as "an active movement by which insects seek resources." Insects must acquire food, mates, oviposition sites, nesting sites, and refugia sites for growth, development and maintenance. Search behaviour has been extensively researched in visual predators which has three types of search strategies that have been identified (Pietruszka, 1986; O'Brien *et al.*, 1990). All essentially involve positioning prey species within the active space of the predator where it is visually detected and subject to an attempted capture or strike. Ambush search is a term used to describe behaviours whereby predators sit and wait for prey to come into their active space and is often used when prey densities are high and the prey species are highly mobile (Jaegar and Barnard, 1981; Formanowicz and Bradley, 1987). In contrast, a cruise search strategy requires a predator to continuously move through the environment attempting to bring prey into their 'active space' and this strategy works well for prey that are sparsely located but highly conspicuous (Jaegar & Barnard, 1981; Janssen, 1982; Formanowicz & Bradley, 1987). These two search strategies represent two ends of a continuum and between these two end points animals tend to display a 'saltatory' type search strategy that consists of a pause and travel search method (O'Brien *et al.*, 1990). The strength of a predator depends on both the speed and the sensitivity of its searching behaviour (Kareiva, 1990). Searching strategies are defined as a set of rules of movement and scanning that result in prey encounter (Smith, 1974a).

Chapter - VI: Biology and Life table

Introduction

Life table is a systematic presentation of survival and mortality in a population and the environmental factors that cause mortality (Pedigo and Zeiss, 1996). In contrast to a life table, a fertility table expresses a schedule of births as adult reach reproductive maturity, age and dies (Southwood, 1978).

Studies on the biology and the construction of a life table for a predator species is an important component in the understanding of its population dynamics (Carey, 1993). Life table parameters are also essential to know the general biology of an insect (Abdel-Salam, 2000). Moreover, life table studies are fundamental to population ecology and give the most comprehensive description of the survivorship, development, and reproduction of a population. The theory and methods of the life table are discussed in most ecology textbooks (Price, 1997, Ricklefs and Miller, 1999). The collection of life table data for related species at different trophic levels in a food chain is a basic and important task for conservation (Bevill and Louda, 1999) and pest management (Naranjo, 2001).

Demographic information can be useful for projecting population growth, timing pesticide applications and designing insect mass rearing programmes. In traditional life tables (Lewis, 1942; Leslie, 1945, 1948; Birch, 1948), only female individuals are taken into consideration, and the means of the durations of developmental stages are used to construct age-specific survival rates and age-specific fecundity for the "female" population (Birch, 1948, Pianka, 1994).

Chapter - VII: Mass rearing

Introduction

Biological control technology has taken three basic forms in its century of existence: conservation, classical importation, and augmentation (Nordlund and Legaspi, 1996). The augmentation of entomophages is imperative for successful biocontrol programmes against many key insect pests in agroecosystems since it increases their population or enhances their beneficial effects (Rabb *et al.*, 1976; Cohen *et al.*, 1999). Augmentation of entomophages in the laboratory or in an insectary facilities their inoculative or inundative release. But it is neither easy nor inexpensive, especially when you have to grow the pest too. Augmentation of entomophages will be successful and viable only when adequate number of organisms of suitable quality is economically mass reared (Ambrose, 2010).

An essential pre-requisite to field augmentation is an effective mass rearing method. Mass rearing of entomophagous insects in the laboratory and releasing them in fields to combat pest species form an important part of pest management (Singh, 1977). Leppla and King (1997) pointed out that biocontrol agents should be at least an order of magnitude less expensive than they are at present to make biological control more cost effective. The expensive mass rearing on natural prey, requirement of space and reliability of rearing at two or three trophic levels of organism to produce entomophages and seasonality of host plants and host /prey warrants and justifies the efforts to develop artificial diet based automated mass rearing system. Therefore, several laboratories have attempted to develop artificial diets for mass rearing of biological control agents. Also, the availability of an artificial diet facilitates automation of a rearing system, which should increase capacity, reduce costs and improve the quality (Nordland and Greenberg,

Chapter - VIII: Chemical Ecology

Introduction

All the organisms in an ecosystem are linked biochemically and their relationship is obvious in food chains and food webs. If simplest or linear food chains in a generalized food web are considered, it contains at least three trophic levels having feeding links with each other. In this tritrophic interaction the member of lower trophic level is forced to evolve, to reduce feeding by higher trophic level; whereas the members of higher trophic levels evolve to increase consumption (Price *et al.*, 1980). Prey location in a complex environment, filled with different plants and animal species, is a complex task. Predatory and parasitic insects have specialized sensory nervous systems that allow them to use a variety of cues to find and identify target organisms. Cues can be physical such as colour, sound, shape and size as well as chemical and these may be useful for long or short range attraction to prey.

Chemical and/or physical cues from the host, the substrate and associated material and/or organisms play a fundamental role in mediating the different steps of host selection (Vinson, 1984, 1985, 1991, 1998; Schmidt, 1991; Vet and Dicke, 1992; Vet *et al.*, 1995). Volatiles are important cues for many arthropods. Many, if not most, insects use odours to find food and mates or to avoid predators and competitors. The food of arthropods is selected to produce as few volatiles as possible to reduce the probability of being detected and eaten. However, volatiles may indispensable for some life stages. Hence, volatiles are likely to be produced only when they are essential in the life-history of an organism or when they are an inevitable by-product of some other essential process and whenever produced, they might be used by other species (Hochberg *et al.*, 2003). Use of chemicals emanating from the host and its by-products which enhance the behavioural

Chapter - IX: Field Cage Evaluation

Introduction

Biological control has been increasingly used in crop protection over the past 30 years, particularly for greenhouse crops, because an enclosed environment makes treatment easier to apply: the crop is subject to less environmental stochasticity than in an open field, and only a limited number of pests develop, so that only a relatively small number of the natural enemy species has to be introduced (van Lenteren, 2000).

A variety of arthropod predator/prey complexes have been studied by enclosing entire rows of crop plants in field cages (Ridgway and Vinson, 1977). These investigations mostly determined average predation levels for representative populations opposed to individual insects. While these data are adaptable for system modelling, it is often difficult to eliminate the error caused by predators from the field.

The aspect of release methodology that commonly requires some decision is whether to place agents initially into field cages (or sleeve cages) stoked with host or not. Field cage studies make prediction of the population of pests and their natural enemies easier and are more reliable than in filed situation (van Lantern and Woets, 1988; Simmons and Minkenberg, 1994). To evaluate the impact of natural enemies, exclusion cages are used. The cages are designed to keep natural enemies out, and allow the pest population to build up in the cage in the absence of natural enemies.

The biocontrol potential of reduviids has been evaluated by Livingstone and Ambrose (1978); Richman *et al.,* (1980), Singh (1985), Singh and Gangrade (1975), Kumaraswami (1991), Ambrose and Claver (1999a) and Claver and Ambrose (2000b, 2001a, b; Grundy *et al.,* 2000a, b; Grundy and Maelzer, 2000b), Ravichandran (2004).

Chapter - X: Large Scale Release

Introduction

Biological control is a good option to complement the integrated control of pests. There are two ways of utilizing natural enemies of insect pests in agricultural systems. One is to preserve existing predators and parasitoids and another is to mass rear natural enemies for augmentative releases to regulate the population density of the target insect pest.

Generalist predators of insects are often expected to be important for controlling pests in agricultural systems (Altiera, 1995). The intuitive prediction is that increasing the density of generalist predators in a crop should subsequently increase predation on pests (Chang and Kareiva, 1999; Walsh and Riley, 1868).

Despite the possibility of intraguild predation, generalist predators contribute to the biological control of pests in crops such as rice (Settle *et al.*, 1996), soyabeans (Carter and Rypstra, 1995), grains (Lang, 2003), alfalfa (Snyder and Ives, 2003) and vegetable gardens (Snyder and Wise, 2001).

One of the prejudices against generalist predators is that they cannot regulate [maintain an organism's population density over an extended period of time between characteristic upper and lower limits (DeBach *et al.,* 1976)] a pest population because no density dependent relationship exists. However, in many agricultural systems, regulation is not the goal; instead, the goal is often an immediate one-time or series of pest population reductions. Such reductions can be accomplished by appropriate releases of generalist predators that can and do attack the target pest. In addition, because generalist

Chapter - XI: Synchronization and Colonization

Introduction

Field testing is an important step in evaluating natural enemies for biocontrol. To establish the potential of any candidate, convincing empirical demonstrations are essential (Cloutier and Bauduin, 1995). Predator abundance and/or species composition may be affected by cultivation practices, thereby increasing or diminishing predator's pressure (Sheehan, 1986; Russell, 1989; Andow, 1991 and Ramert, 1996).

For a natural enemy to be an effective biological-control agent in such disturbed habitats, it should possess the following attributes (Ehler, 1990): i) colonizing ability, so that the natural enemy can keep pace with the spatial and temporal disruptions of the habitat, ii) temporal persistence, so that following colonization, the natural enemy can maintain its population, even in the absence of the target pest species and iii) opportunistic feeding habits, so that the natural enemy can rapidly exploit a food resource, including the sudden appearance of a pest population.

The ability of introduced predators to survive and successfully seek out their prey is basic to the success of a biological pest control programme using exotic control agents. Agricultural systems frequently display explosive herbivore outbreaks, while less-disturbed natural communities rarely do. This has led to the suggestion by agroecologists that restoring some elements of biodiversity to agricultural systems may improve natural pest control (Pimentel, 1961). Messenger and van den Bosch (1971) reviewed requisites of introduced biological control agents with particular emphasis upon their adaptability to new environment. Studies of the life history and feeding habits are the logical early steps in the consideration of new or imported predator species (Greene, 1973).

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