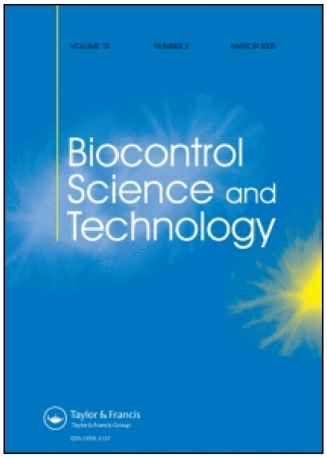

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REVIEW

Ecology and Biocontrol Potential of a Scale-Predator, *Chilocorus nigritus*

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Chilocorus nigritus *(Fabricius) is a common predator of scale insects, especially Diaspididae. It is an effective colonist, native to India and may easily establish in pest prevalent regions. Several attempts have been made in the recent past to exploit it for the biocontrol of diaspids infesting sugarcane, citrus and other horticultural crops. The scattered information on its global distribution, foraging, prey range and predation habits, growth and development, reproduction, mass rearing and releases is reviewed. The interpretation of the empirical data has been made and inferences drawn, wherever needed. There is an asymmetry in the literature available, since much emphasis has been given to sampling, mass rearing and field releases of the predator, whereas its ecological and reproductive aspects are poorly dealt with. There are a number of gaps in the information, such as, influences of its age, reproductive, adaptive and survival strategies, its role in the guild and artificial diets which require further investigation.*

Keywords: Chilocorus nigritus*, Coccinellidae, Diaspididae, scale insects, diaspids*

INTRODUCTION

Increasing awareness of the implications of pesticides on environment and biodiversity have led to the introduction and subsequent manipulation of the natural enemies of phytophagous pests, like scale insects (Superfamily Coccoidea, which include families Diaspididae, Coccidae, Pseudococcidae, Eriococcidae, etc.), which have tremendous damage potential. Natural enemies, such as, parasitoids and predators have been released in pest prevalent areas; of these, the former were more successful in depleting the pest populations (De Bach, 1964). A number of parasitoids, especially the species of *Aphytis* and *Metaphycus* along with *Comperiella bifasciata* Howard, *Habroleptis dalmani* (Westwood) and *Aphycus timberlakei* Ishii, have played a major role in the management of scales: in particular, *Aonidiella aurantii* (Maskell), *Aonidiella citrina* (Coquillett), *Saissetia oleae* (Bernard) and *Asterolecanium*

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variolosum (Ratzeburg) (De Bach, 1964). The success of biological control agents is largely dependent on their high searching efficiency, host specificity and the low generation time ratio between the bioagent and the target pest species (De Bach, 1964; Dixon, 2000).

Certain predators, in particular, ladybeetles (Coleoptera: Coccinellidae) are also potential natural enemies of the scales along with other phytophagous pests, *viz*. aphids, adelgids, aleyrodids, psyllids, etc. (Dixon, 2000; Omkar & Pervez, 2003). Three books have been published on ladybeetles during the last decade (Majerus, 1994; Hodek & Honek, 1996; Dixon, 2000). Of these, Majerus (1994) described the natural history of British ladybeetles, Hodek and Honek (1996) comprehensively reviewed the ecology of Coccinellidae, and Dixon (2000) presented an analytical account of prey–predator relationships of predaceous ladybeetles and their utility in biocontrol of target pest species. The ecology of certain ladybeetles, *viz*. *Cheilomenes sexmaculata* (Fabricius) (Agarwala & Yasuda, 2000) and *Coccinella septempunctata* Linnaeus (Omkar & Pervez, 2002) has been recently reviewed.

Amongst predaceous ladybeetles, species of *Chilocorus* are important scale-predators, capable of removing heavy infestations and thereby increasing the crop yields (De Bach, 1964; Omkar & Pervez, 2003). Earlier *Chilocorus* was known to contain 62 predaceous species (Leeper, 1976; Samways *et al*., 1999) but three new Oriental species, *viz*. *Chilocorus melas* Booth, *Chilocorus subindicus* Booth and *Chilocorus gracilior* Booth have recently been added to the list (Booth, 1998). *Chilocorus nigritus* (Fabricius) is one of the Oriental species of ladybeetles. It is native to the Indian subcontinent and an active predator of many insects, especially the scales (Omkar & Bind, 1995; Omkar & Pervez, 2003). It has been successfully utilized as a bioagent in many biocontrol programmes and classically introduced in scale-prevalent regions time and again (De Bach, 1964; Samways, 1984, 1998). The parasitoids and *C. nigritus* are jointly responsible for declining the population of *A*. *aurantii*, infesting citrus orchards of South Africa (De Bach, 1964; Samways, 1986a,b; Hattingh & Samways, 1991a; Magagula & Samways, 2000). In this region, the adults of *C. nigritus* shuttle between citrus orchards infested with *A. aurantii* and giant bamboo plants harbouring diaspid, *Asterolecanium miliaris* (Boisduval) (Samways, 1984; Hattingh & Samways, 1991b). Success of *C. nigritus* and other coccidophagous beetles has been attributed to their high searching efficiency and quick response to the changes in the prey density (De Bach, 1964; Hattingh & Samways, 1991a; Dixon, 2000). Evidence revealing successful utilization and establishment of *C. nigritus* in the past prompted us to gather scattered information and to formulate guidelines that may be beneficial for its utilization in insect pest management. Owing to some ambiguous information on certain important aspects of the predator, suggestions have been made for further research. Interpretations and inferences from the empirical data have been drawn, wherever required.

GENERAL CHARACTERISTICS

Chilocorus nigritus originates from the Indian sub-region, classified as Climatic Zonobiome II (tropical with summer rainfall) (Samways, 1989). Biogeographical studies revealed that it prefers hot and humid summers and cool dry winters (Samways, 1989).

Life History

The female ladybeetle lays bright yellow spindle-shaped eggs (singly) on the substrata to which they are attached by one of their ends (Puttarudriah & Channa Basavanna, 1953). The early first instars hatch out and usually moult thrice to undergo four larval instars (Ponsonby & Copland, 1996). Interestingly, there is also a report of five larval instars in this species (Fitzgerald, 1953), which was supported by Chazeau (1981). However, these two far dispersed reports cannot be taken seriously until they receive further corroborative support.

The greyish yellow larvae beset with hair-covered spiny processes on the dorsal surface have characteristic dark patches on second, third and seventh to ninth segments, which impart a banded appearance. Mature fourth instars congregate inside the concavity of crumpled leaves to pupate (Puttarudriah & Channa Basavanna, 1953). The adult ladybeetles are easily recognizable owing to their almost semi-spherical shape with sizes ranging from 3.00 to 5.50 mm (Puttarudriah & Channa Basavanna, 1953; Samways, 1984; Omkar & Bind, 1995). They are characterized by all black and highly shiny elytra with orange areas between the eyes and on the antero-lateral tips of the pronotum.

Sexual Dimorphism and Sex-Ratio

Sexual dimorphism is prominent in *C. nigritus*. The two sexes can be identified by the patches present on their sternite (abdominal plates). In males, particularly the older ones, the lateral areas of the fourth and seventh sternite are dark; however, similar patches are absent in females (Samways & Tate, 1984). The eighth sternite is weakly scalloped at the edge in the males but is rounded in females (Samways & Tate, 1984). The sex-ratio (male:female) varied from 1:1.44 to 1:3.55 in the orchard infested with *Aspidiotus nerii* Bouché (Erichsen *et al*., 1991). The reason for this high female-biased ratio was its relatively high longevity. The sex-ratio (male:female) between the young adults at two prey-sites of South Africa, *viz.* Hazyview and Tshaneni was 1:2.07 and 1:1.71, respectively (Samways & Tate, 1984). Contrary to the field observations, the sampling of the older adults of age between 2 and 6 months in an insectary revealed a sex-ratio (male:female) of 1:0.42 (Samways & Tate, 1984). This led to an interesting conclusion that females become scarce faster than males when in captivity, which may be attributed to the increased mortality of the older females. The reason for this increased mortality of the older females in captivity is unclear, since in the fields they are better adapted to the stressful conditions and highly tolerant to hazardous pesticides (Schoeman, 1994).

FORAGING

The individuals of *C. nigritus* are positively phototactic and negatively geotactic and tend to use prominent features of plants, such as leaf veins and margins, to aid their searching behaviour (Ponsonby & Copland, 1995). Since the prey species also show similar photo- and geotaxes, such responses of the predators enable them to concentrate at sites of high prey density.

The foraging patterns in adults and larvae were invariably different, as the former were capable of locating prey through both visual and olfactory cues over short distances, while the latter were more dependent on tactile cues (Hattingh & Samways, 1995). Both adults and larvae altered their foraging patterns from extensive to intensive search culminating in prey consumption (Hattingh & Samways, 1995). If prey were not encountered during the intensive search they reverted back to extensive search (Hassell & Southwood, 1978; Carter & Dixon, 1984). *Chilocorus nigritus* has a hierarchical prey-location mechanism, which involves host habitat location based on olfactory responses. After an encounter with prey, the searching activity was modified by decreased orthokinesis (forward speed) and increased klinokinesis (frequency and intensity of turning) (Ponsonby & Copland, 1995). Orthokinesis increased in starved beetles in the presence of host plant volatiles. A strong directional response was exhibited when plant odour was supplemented with prey odour. These mechanisms enable the predator to remain active in the favoured host habitats and enhance their activity in prey searching. The females were highly attracted to their hosts, walked further and spent more time searching for them in the presence of host plant, *Solanum melongena* Linnaeus and *Abgrallaspis cyanophylli* (Signoret) odours (Ponsonby & Copland, 1995).

Chilocorus nigritus was visually attracted to prominently silhouetted features, such as, horizon with individual trees (Hattingh & Samways, 1995). Vertical lines of the plants were more attractive than the horizontal ones. The plants that were regularly encountered by the predator have similar leaf-structure, i.e., ovate, elliptic or oblong, e.g , citrus, guava, mango, banyan, coffee and fig plant leaves, which suggests that leaf shape is also an important visual cue for prey-location (Hattingh & Samways, 1995).

Prey intake enhanced area-restricted foraging pattern in adults (Hattingh & Samways, 1991b), as it probably facilitates prey-recognition, as in other species of *Chilocorus* (Podoler & Henen, 1986; Hattingh, 1989). In South Africa, in the absence of essential prey (*Aspidiotus nerii*), the predator shuttles to alternative prey sites (e.g., *Asterolecanium miliaris* on giant bamboo plants, *Dendrocalamus giganteus* Munro), which act as reservoirs and are a major reason for the success of *C. nigritus* in biocontrol of scales (Hattingh & Samways, 1991b). This aspect of the predator is being exploited for the management of scales by growing alternative host plants in the periphery of the affected orchards (Hattingh & Samways, 1991b), which may serve as valuable reservoirs for the biocontrol agents. However, only peripheral plantations harbouring less preferred alternative prey are used in order to minimize migration from orchards to reservoirs.

PREDATION

Prey Range

Chilocorus nigritus feeds on a variety of insect pests. Its aphidophagous habit has been recorded from Kanpur, India (Sharga, 1948). The adults were reported feeding on aphids, *Lipaphis erysimi* (Kaltenbach), *Brevicoryne brassicae* Linnaeus, *Myzus persicae* (Sulzer) and *Aphis nerii* Boyer de Fonscolombe from the Lucknow regions of Uttar Pradesh (Omkar & Bind, 1995). It was considered an incidental predator of *Aphis craccivora* Koch (Agarwala & Ghosh, 1988).

Chilocorus nigritus preys on soft green scale, *Coccus viridis* (Green) infesting acid lime in India (Mani & Krishnamoorthy, 1998). Both larvae and adults feed on the spiralling whitefly, *Aleurodicus dispersus* Russel (Mani & Krishnamoorthy, 1999). The larvae feed and complete their development exclusively on *A. dispersus* in the laboratory (Mani & Krishnamoorthy, 1999). The predator is known to be a natural enemy of a number of scale-insects infesting coconut, *viz. Aspidiotus destructor* (Signoret), *Ceroplastes actiniformis* Green, *Vinsonia stellifera* (Westwood), *Coccus acutissimus* Green, *Coccus hesperidum* Linnaeus, *Pseudococcus citriculus* Green, *Palmicultor* sp. and *Pseudaulacaspis* sp. (Jalaluddin *et al.,* 1991). It is a voracious feeder on red scale, *A. aurantii* (Samways, 1989), and also preys on diaspids, *Chrysomphalus aonidum* (Linnaeus), *Lepidosaphes beckii* (Newman), *Pseudaulacaspis pentagona* Targioni-Tozzetti and *Aulacaspis tubercularis* Newstead (Schoeman, 1994). The predator was identified feeding on the scales, *Parlatoria blanchardi* Hirst, *Hemiberlesia lataniae* (Newstead) and *Phoenicococcus marlatti* Cockerell on date plants in Gujarat, India (Murlidharan *et al*., 1992; Murlidharan, 1993).

Feeding Behaviour

The sharp pointed mandibles help the ladybeetle in the complete removal of the scale from the fruit surface (Samways & Wilson, 1988). Feeding behaviour for larvae of *C. nigritus* was investigated using cyanophyllum scale, *Abgrallaspis cyanophylli* as prey (Ponsonby & Copland, 2000). First instars chewed through the newly formed scale cover and sucked out the body juices, leaving the cuticle behind, whilst the other three instars completely removed the scale cover and sucked out the body contents, leaving the cuticle behind or partially eaten. Rarely was the entire insect eaten (Samways & Wilson, 1988; Ponsonby & Copland, 2000). The piercing/puncturing of the scales leads to their rapid dehydration (Foldi, 1990). The total number of scales killed (which include first instar, second instar, puparial males and adult females) by first, second, third and fourth male larval instars was 122, 96, 135 and 160 and by female instars was 104, 107, 127 and 170, respectively (Ponsonby & Copland, 2000). The differences in prey consumption by the larval instars, when compared amongst the two sexes, however, did not vary significantly (Ponsonby & Copland, 2000).

Prey Consumption and Preference

The predatory potential and prey consumption by the larvae and adults of *C. nigritus* on nine (20–25-day-old) diaspid species, *viz. Melanaspis glomerata* (Green), *Quadraspidiotus perniciosus* (Comstock), *Aspidiotus destructor, H. lataniae, Aonidiella aurantii*, *Chrysomphalus aonidum* (Linnaeus), *Aonidomytilus albus* (Cockerell) and *Lepidosaphes cornutus* Green was studied by Jalali & Singh (1989). The larvae preyed on 29.7–38.0 diaspids/day, while adults consumed 60.7–71.4 diaspids/day. The adults preferred *Q. perniciosus*, while larvae preferred *Aspidiotus destructor* (Jalali & Singh, 1989). The fourth instars consumed maximum number of diaspids (55.6), followed by the third instars (34.8) (Jalali & Singh, 1989). Adults consumed on an average 20.9 diaspids/day with a total lifespan consumption of 1317.1 diaspids (Jalali & Singh, 1989).

The adults preferred *Aonidiella aurantii* (21.6 scales/day) to *Aspidiotus nerii* (11.4 scalea/day) (Samways & Wilson, 1988), while the larvae preferred *Aspidiotus nerii* over *Aonidiella aurantii, Asterolecanium miliaris* and *Chrysomphalus aonidum* (Linnaeus) (Hattingh & Samways, 1992). Ponsonby and Copland (2000) observed that the first instar *C. nigritus* can easily prey on second instar nymphs of *Abgrallaspis cyanophylli*, contrary to an earlier report (Samways & Wilson, 1988), that stated an inability for first instar larvae to prey on second instar nymphs of other scale insects, such as *Aspidiotus nerii* (morphologically similar to *Abgrallaspis cyanophylli*). This revealed flexibility in foraging patterns of first instar of *C. nigritus* when provided with second instars of *Abgrallaspis cyanophylli*, indicating its suitability over *Aspidiotus nerii* (Ponsonby & Copland, 2000).

Chilocorus nigritus readily fed on *Aonidiella aurantii* parasitized by *C. bifasciata* (Samways & Wilson, 1988). This suggests that parasitization perhaps increased the likelihood for reducing the combined impact of these two natural enemies on the scale population.

GROWTH AND DEVELOPMENT

Empirical data on the biotic potential of *C. nigritus, Chilocorus bijugus* (Mulsant) and *Sticholotis madagassa* (Weise) on nine diaspids showed that the former was the most potent scale predator (Jalali & Singh, 1989). The development of *C. nigritus* was fastest (32.3 days) on *Q. perniciosus* in comparison to the other two. The duration of the egg stage, first, second, third and fourth larval instars of *C. nigritus* was 6.1, 3.5, 3.8, 3.8 and 3.8 days, respectively, when fed on scale, *P. blanchardi* (Murlidharan, 1994). The prepupal and pupal periods lasted for 2.5 and 6.6 days, respectively (Murlidharan, 1994). The longevity of adult male and female was 50.2 and 76.1 days, respectively.

Influence of Biotic and Abiotic Conditions on Development

Prey substitution temporarily reduces the fitness, i.e., immature development and adult reproduction in *C. nigritus* (Hattingh & Samways, 1992). It may be considered adaptive, as reduced oviposition in presence of an unfamiliar prey also reduces the risk of serious repercussion to the fitness of progeny (Hattingh & Samways, 1992). Prey substitution had a more prominent effect on the larval development than on adult maintenance, emphasizing the greater sensitivity of larvae to the change in diet (Hattingh & Samways, 1992). Larvae were not generally exposed to two prey types in the fields, as adults select the prey patches for them.

Chilocorus nigritus may be one of the species most tolerant to the extremes of temperature (Hattingh & Samways, 1994). Thermal tolerance of different species of *Chilocorus* is shown in Table 1. Temperature tolerance is an adaptive strategy of the predator, which has helped in its establishment in the tropical and sub-tropical regions. Temperatures of 20°C and below were not suitable for the survival and development of first instar of *C. nigritus* due to high mortality (Ponsonby & Copland, 1996). The theoretical lower threshold for survival of first

TABLE 1. Percent survival of *Chilocorus* sp. at various constant temperatures (*n* ranged between 14 and 21) (after, Hattingh & Samways, 1994)

Species	Temperature (°C)						
	3	10	17	24	31	38	41
Chilocorus nigritus (Fabricius)	100	88	100	95	95	95	0
Chilocorus bipustulatus (Linnaeus)	85	94	100	100	100	100	0
Chilocorus cacti (Linnaeus)	100	95	95	95	100	100	0
Chilocorus distigma (Klug)	100	100	100	100	100	100	0
Chilocorus infernalis Mulsant	85	100	100	100	95	84	0
Chilocorus simoni Sicard	100	93	94	100	100	88	0

instars was 16.6°C. The development period was 74.5, 57.9, 48.0, 34.0, 28.6 and 25.2 days at temperatures of 20, 22, 24, 26, 28 and 30°C, respectively (Ponsonby & Copland, 1996). The developmental rate thus, increased with the increase in temperature, but the relative duration of different instars was not affected (Ponsonby & Copland, 1996). The preimaginal period at cyclic temperatures (14–30°C) was 47.0 days (Ponsonby & Copland, 1996). Unexpectedly, much similar larval durations of first and fourth instars, which were relatively larger than second and third instar durations, were also reported by Ponsonby and Copland (1996).

The feeding rate of *C. nigritus* increased with increase in temperature, reaching a peak at 30°C and thereafter declined (Hattingh & Samways, 1994). The daily oviposition, percent viability and adult weight after 40 days of exposure on *Aspidiotus nerii* was 4.3 eggs, 74.0% and 8.8 mg, respectively, at optimum constant temperature and 2.2 eggs, 71.0% and 8.4 mg at fluctuating temperatures (3–38°C), showing that constant temperatures are more suitable than fluctuating ones (Hattingh & Samways, 1994). Cold exposure probably induces a pause in spermatogenesis and/or sperm mortality in spermathecae at fluctuating or cyclic temperatures, thus reducing the reproductive ability of adults (Ponsonby & Copland, 1998).

Between 20 and 30°C, an increase in constant temperatures increased the rate of scale consumption by the predator from 3.94 to 8.83 scales. The feeding rate was highest at a constant temperature of 26°C, with females being more voracious than males (Ponsonby & Copland, 2000). The cyclic temperature (14–30°C) increased the voracity in both sexes, which was higher than that observed at 26°C (Ponsonby & Copland, 2000). Mean assimilated food intake varied from 0.097 mg/day at 13°C to 1.432 mg/day at 30°C. However, intake at the cycling temperature was significantly higher than that at constant temperatures (1.98 mg/day). A mean of 16.24 mg of *A. cyanophylli* was required for larvae of both the sexes to complete development (Ponsonby & Copland, 2000). When *C. nigritus* larvae were reared on two diaspids, *viz. Asterolecanium* sp. and *A. nerii*, their developmental rate was faster when first fed the former species (18.7 days). It was slower (24.0 days) when *C. nigritus* larvae were first fed on the latter prey (Hattingh & Samways, 1991b). No significant difference in various biological attributes of *C. nigritus* was found at different levels of R.H. (33–75%) (Ponsonby & Copland, 1998).

REPRODUCTION

The pre-mating period of *C. nigritus* was 5.4 days at 24°C (Ahmad, 1970). Mating lasted for 28 min and females oviposited 10 days after the first mating (Ahmad, 1970). Mostly, the eggs are laid singly or in small groups constituting two to four eggs in the shields of dead scales (Fitzgerald, 1953; Ahmad, 1970; Dorge *et al*., 1972). Females also oviposit on the silk of spider webs or any other substrata composed of loose fibres (Samways & Mapp, 1983) and on scale-infested leaves (Puttarudriah & Channa Basavanna, 1953).

The reproductive attributes of *C. nigritus* have been reported for several hosts with fecundity ranging between 90 and 370 eggs (Table 2). A recent study illustrated that optimum

TABLE 2. Reproductive response of female ladybeetle, *C. nigritus*

Prey species	Pre-oviposition period (days)	Fecundity (eggs)	Oviposition period (days)	Oviposition rate	Reference
Aonidiella orientalis (Newstead)	15.4	*	*	3.1	Ahmad (1970)
Aspidiotus glomeratus G. Labdev	1–3	24	1–3	*	Dorge *et al*. (1972)
Aulacaspis tegalensis	23.0	370	24	*	Greathead & Pope (1977)
Melanaspis glomerata	12.0	80.0	*	*	Jalali & Singh (1989)
Quadraspidiotus perniciosus	12.0	86.0	*	*	Jalali & Singh (1989)
Aspidiotus destructor	12.0	93.0	*	*	Jalali & Singh (1989)
Aulacaspis tubercularis	17.0	87.0	*	*	Jalali & Singh (1989)
Hemiberlesia lataniae	15.0	79.0	*	*	Jalali & Singh (1989)
Aonidiella aurantii	16.0	81.0	*	*	Jalali & Singh (1989)
Chrysomphalus aonidum	17.0	72.0	*	*	Jalali & Singh (1989)
Aonidomytilus albus	16.0	57.0	*	*	Jalali & Singh (1989)
Lepidosaphes beckii	13.0	71.0	*	*	Jalali & Singh (1989)
Aspidiotus nerii	14.0	*	*	4.6	Hattingh & Samways (1994)
Parlatoria blanchardi	5.0	151.2	*	*	Murlidharan (1994)
Abgrallaspis cyanophylli	*	1361	180	5.92	Ponsonby & Copland (1998)

*Data not available.

temperature and prey quality enhances fecundity (Ponsonby & Copland, 1998). *Abgrallaspis cyanophylli,* as prey, enhanced fecundity with a slight variation in number of eggs laid at different constant temperatures between 20 and 28°C (Ponsonby & Copland, 1998). A temperature of 26°C is comparatively more suitable, yielding a high fecundity of 1361 eggs. One female laid 1890 eggs, which is the highest record to date (Ponsonby & Copland, 1998). The maximum fecundity also resulted in a prolonged reproductive period of 180 days, with one ladybeetle having an oviposition period of 238 days. The peak mean reproductive rate was attained at a reproductive age between 30 and 50 days (Ponsonby & Copland, 1998). In spite of this high fecundity, the mean reproductive rate (5.92 eggs/day) was similar to that recorded by other workers. The prey-alteration and prey-substitution inhibited the reproductive activity of the females, delaying the oviposition for several days (Hattingh & Samways, 1992).

BIOLOGICAL CONTROL, REARING AND RELEASES

Chilocorus nigritus has been colonized in a number of countries to control scale infestations. Its releases have especially been widespread and effective in regions of South Africa, particularly in the climatic regions of Central and South Africa (Table 3) (Samways *et al*., 1999). The few unfruitful attempts can be attributed to inappropriate climatic conditions.

Individuals of *C. nigritus* exported from India were introduced effectively in Oman during 1985 for the biocontrol of *Aspidiotus destructor* (Kinawy, 1991). A total of 683 adults were released during January–April 1985, which resulted in a rapid build-up of predator numbers and a subsequent decline in the pest population. Two years after release, the median number of pests per leaf area was between 0 and 49.7, whereas pest number ranged from 174.8 to 285.0 before the release. Number of *C. nigritus* eventually reached 38.2–144.5 adults and larvae per tree. Infestation of *Aonidiella aurantii* is a common problem in South Africa. After the establishment of *C. nigritus* in the region, the pest problem is now not so acute. When the host plants were completely encrusted by red scale, the predator density reached two beetles per leaf and four beetles per orange (Hattingh & Samways, 1990).

The success of *C. nigritus* may be due to low intraspecific competition (Hattingh & Samways, 1990). The congregation of predators at the prey-site results in mass destruction of scales, with minimal mutual interference; varying predator densities do not affect feeding rates (Hattingh & Samways, 1990). This behaviour is akin to those of parasitoids, as they do

TABLE 3. Introduction of *C. nigritus* at different places

Place of introduction	Status	Reference
Agalega	Established	Greathead (1971)
Seychelles	Established	Hill & Blackmore (1980)
Ghana/Brazil	Established	Samways (1989)
Guam/Hawaii	Established	Davis (1972)
Israel	Failed	Argov & Rossler (1988)
Java	Established	Chazeau (1981)
Kenya/Tanzania	Established	Greathead & Pope (1977)
Madagascar/New Caledonia	Established	Samways (1989)
Oman	Established	Kinawy (1991)
Reunion	Established	Chazeau *et al.* (1974)
American Samoa	Established	Gutierrez (1978)
Society Islands	Established	De Lobel (1978)
Turkey	Established	Uygun & Sekeroglu (1987)
Soloman Islands	Established	Chazeau (1981)
Swaziland/Zimbabwe	Established	Samways (1984)
Uganda	Failed	Williams & Greathead (1973)

not disperse with increased crowding and there is no temporary cessation in the foraging pattern after encountering conspecifics.

Another reason for its success is the ability of the adults and mature larvae to completely remove the adult female scales from the fruit surface using their sharp pointed mandibles (Samways & Wilson, 1988). Owing to their faster feeding rate, the adults are more preferred than the eggs and young larvae in biocontrol operations. The introduction of the predator's eggs in the scale-infested area is not advisable, since most of the hatched larvae starve when the scale population is composed mostly of adult females (Samways & Wilson, 1988). There were several field reports where egg introductions at severe red scale populations resulted in high early larval instar mortality. Therefore, the release of late larval instars and adults was advised. The total prey requirement of *C. nigritus* for the development of immature stages is 500 individuals of *Abgrallaspis cyanophylli* or more. Of these, more than 100 first instars of *Abgrallaspis cyanophylli* are required for the first larval stage alone (Ponsonby & Copland, 2000). Thus, high prey density is required for predator maturation, which leads to the effective control of scales.

Chilocorus nigritus was more efficient in removing medium and medium–high densities of scale (15.8 and 23.5 scales/cm^2) than at very high ones ($>$60.0 scales/cm^2) (Erichsen *et al.*, 1991). It has a tendency to avoid rotten fruits infested with high scale levels as compared to those with medium scale infestation. There is possibly a built-in mechanism that allows the adults to avoid such rotten fruits on which their offspring would not survive. Thus, its augmentative releases are recommended at the sites with medium density infestation of prey (Erichsen *et al.*, 1991).

The techniques of mass rearing of this scale predator have been described in detail (Samways & Mapp, 1983; Samways & Tate, 1986; Sadakathulla, 1993; Anonymous, 1995). The predator can be multiplied on several diaspids, such as, *A. aurantii, H. lataniae* and *M. glomerata* (Anonymous, 1995). Sadakathulla (1993) described a method for the mass production of *C. nigritus* by rearing it on *A. destructor,* a coconut pest in India. Prolific rearing can also be done by using a honey–agar diet as an alternative source of food instead of diaspids (Anonymous, 1995). Honey–agar is prepared by adding 1 l water to 10 g agar–agar powder, 200 g sugar and 400 g honey (Anonymous, 1995). Certain artificial diets, which can be used for the mass rearing of *C. nigritus* have also been suggested by Hattingh and Samways (1993). Freeze-dried artificial diets based on broods of *Apis mellifera* Linnaeus or *Vespula germanica* (Fabricius) and pupae of *Epiphyas postvittana* (Walker) for laboratory rearing of *Chilocorus* species were also recommended (Henderson *et al.*, 1992). The diet based on brood of *V. germanica* was the most successful.

Chilocorus nigritus is rarely attacked by pathogens or parasitoids and this further aids its successful establishment. Occasionally, the fourth instar larvae are attacked by the parasitoid, *Homalotylus* sp., but the percentage of parasitism is usually very low in nature (Puttarudriah & Channa Basavanna, 1953).

CONCLUSION

Chilocorus nigritus has proved its efficacy as an important biocontrol agent of scale-insects in the past. Its successful establishment in different pest prevalent regions highlights the need for its large scale rearing and further utilization in classical biocontrol. Evidence suggested that once established in an area, it becomes a permanent member of the local fauna and may reinvade the pest ranks time and again by shuttling on to alternative hosts. There is a very low frequency of parasitism of *C. nigritus* in contrast to the other ladybeetles, which facilitates its survival, fitness and production. Only a single parasitoid, *Homalotylus* sp. has been reported, so far attacking it.

Though *C. nigritus* is one of the most successful bioagents, not only in the family Coccinellidae but also amongst other bioagents, such as parasitoids and other predators, it is generally ignored as compared to other predaceous ladybeetles. Sporadic data are available on its occurrence from the Indian subcontinents. Indian studies are mostly limited to the distributional records with brief information on its biology. In fact, there is little contribution from India on *C. nigritus*, possibly because scale infestation is not a major problem there.

There still remain many gaps in the literature on *C. nigritus* life history traits. Research is needed on the ambiguities surrounding its biological and reproductive attributes, and its adaptive strategies. The role of this predator in a guild, including intraspecific and heterospecific interactions is yet to be explored. Suitable and cost effective diets for the augmentation of the scale predator are lacking. The optimization of abiotic factors is also needed to enhance its reproductive performance. These studies may provide valuable information for more specific and result-oriented utilization of the predator and help reduce the possibilities of occasional failures.

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