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Reaction of the ladybird *Chilocorus nigritus* (F.) (Col., Coccinellidae) to a doomed food resource

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Abstract

The coccinellid *Chilocorus nigritus* (F.), a predator of many scale insects, has become an economically important natural enemy of red scale (*Aonidiella aurantii* [Maskell]) in the subtropical citrus-growing areas of southern Africa. Although relatively easy to mass rear and distribute, there has been speculation that *C. nigritus* does not exploit fruit with very high scale infestations. Experimentation using an alternative prey scale *Aspidiotus nerii* Bouché showed that a range of low to medium-high scale population levels supported increasingly high ladybird densities. At high scale densities, where the host vegetable was imminently doomed, there was a significant drop in beetle densities. At even higher scale densities, where the fruit was already beginning to rot, there was a return in beetle densities to a level equivalent to that on medium-high scale densities. At low to medium-high prey densities, male and female beetles were present in fairly constant proportions. At high prey levels there was an increase in female dominance, yet a strong decrease in dominance at even higher scale levels where the vegetable was already beginning to rot. There appears to be an avoidance of imminently doomed vegetable hosts, yet, in contrast, rotting vegetables have some attraction but more so for males. Commercial insectary rearing of *C. nigritus* would be maximized by using medium-high host scale densities.

1 Introduction

Chilocorus nigritus (F.) is an important biocontrol agent of various diaspidid scale insects (Samways 1984). It is indigenous to India and the Far East (Ahmad 1970) and has been introduced into or naturally invaded various regions, including Mauritius, the Seychelles, East and West Africa, a number of Pacific Islands, and also north-eastern Brazil (Samways 1989). *C. nigritus* appeared of its own accord in southern Africa (Georgala 1979) during the early 1970s. It has since been reared and distributed, but not necessarily established, in all citrus regions in southern Africa to reduce red scale (*Aonidiella aurantii* [Mask.]) populations.

It is most practical to introduce the adult stage into the field (Samways and Wilson 1988; Hattingh and Samways 1991). Although the adults are able to consume all the red scale growth stages, field observations have suggested that these ladybirds do not exploit fruit with extremely high infestations (Samways 1988). Also, a model suggests that the ladybird predation becomes maximized at prey densities above which other natural enemies can no longer control the pest, preventing the scale reaching very high levels and destroying the fruit (Samways 1988). There is possibly a built-in mechanism that allows the adult beetle to avoid such doomed fruits on which the offspring would not survive. This study quantifies in the laboratory the *C. nigritus* feeding response by both sexes to various scale densities. Recommendations are also made on host scale densities appropriate to maximizing *C. nigritus* production in commercial insectaries.

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2 Materials and methods

2.1 Rearing of the prey

C. nigritus was much more readily reared on Oleander scale (*Aspidiotus nerii* Bouché) than red scale in the laboratory (Samways and Tate 1986). In turn, Oleander scale was reared on potatoes (*Solanum tuberosum* L. cv. "Up-to-date") and butternuts (*Cucurbita moshcata* Duch. ex Lam.) (Duch. ex Poir cultivar).

Prior to scale infestation, the vegetables were cleansed by scrubbing in a 2.5 % sodium hypochlorite solution after which each was dipped for 15 sec into a 0.2 % solution of the fungicide, benomyl. The vegetables were then placed out on benches in a closed laboratory to dry at room temperature. Once dry (minimum 24 h), the potatoes were infested with Oleander scale. Infestation took place in a closed insectary with the temperature and humidity controlled at 24 ± 1 °C and 60 % r.h. and a light/dark cycle of 14 h/10 h. After removing potatoes infested with potato tuber moth (*Phthorimaea operculella* Zeller), healthy looking potatoes were placed onto the scale stock-culture. These provided the mother-stock from which the experimental butternuts could be infested. Fresh butternuts were placed upon the mother-stock potatoes so that the scale crawlers could move onto them. Infested butternuts were then stored on shelves to allow the scale to mature.

2.2 Rearing of the predator

Butternuts with a high infestation of scale were placed in boxes housing *C. nigritus*. The boxes were wooden, net-panelled and glasstopped with a sponge lining around the open perimeter to seal the top. Each measured 500 mm × 410 mm, and were 415 mm deep. The adults could freely settle on the butternuts to feed and oviposit. The large interior of the box gave the beetles ample room to fly. This was important to maintain maximal longevity and fecundity of the beetle colony (Samways and Tate 1986). Free water was periodically provided by gently spraying the inside of the box with an atomizer.

Butternuts were removed from the adult cages every three weeks and placed in a larval hatchery to prevent cannibalism of eggs and young larvae by the adults. Rotting butternuts were removed weekly. The hatcheries were wooden and square-framed, with a hardboard bottom and netted sides and top, measuring 200 mm × 200 mm × 200 mm. Newly emerged adults were transferred from the hatchery to the adult cages to boost the stock culture. Both the adult cages and larval hatcheries were kept in a temperature-, humidity-, and light-controlled room (22.5 °C; 60 % r.h.; light/dark cycle of 14 h/10 h) separate from that of the butternut-infestation insectary.

2.3 Beetle and prey-density trials

2.3.1 Levels of host infestation and number of butternuts required

Three butternuts were infested with different levels of prey-density, each with only a single generation of Oleander scale. The densities were established by time allowed for infestation and by regular checking of the number of crawlers by eye. Times for infestation were 6 h, 24 h, and 48 h. Two butternuts per time category compensated for the possibility of a butternut rotting. In addition, heavily infested butternuts and rotting ones with more than one generation were kept aside for use in the trials.

A batch of six butternuts each with an increasingly high level of prey infestation was used per replicate. Butternut infestation ranged from non-infested through to completely infested and rotting (table 1). The batch of six butternuts was then placed randomly in a box with adult *C. nigritus*.

Table 1. **Mean number of Oleander scales per cm² (± 1 S.E.) and level description per infestation**

Infestation	Mean no of scale/cm² (± 1 S.E.)	Level of infestation
1	00.00	non-infested
2	10.27 ± 0.52	low
3	15.84 ± 0.65	medium
4	23.50 ± 0.58	medium-high
5	> 60.0	high
6	> 70.0	high with rotting host vegetable

2.3.2 Recording the number of beetles per infestation

A preliminary trial was conducted to establish when recordings should end. This was because the number of beetles settling on a particular butternut eventually stabilized and further readings were unnecessary. The butternuts were randomly placed in the adult *C. nigritus* cage and the number of beetles on each butternut recorded every hour. The number of beetles was then ranked. The stage at which ranks no longer changed was taken as the time at which the number of beetles per butternut had stabilized and no further readings were taken.

Readings were taken every hour until the cut-off time as established by the preliminary trial. For each experiment, a different batch of butternuts was used. This was to eliminate the possibility that the beetles might avoid surfaces previously visited where no prey was found by individual-specific markers (MARKS 1977), and to reduce previous feeding affecting subsequent foraging behaviour. Seventeen trials were conducted; the results required a $\log(x+1)$ transformation as determined by Taylor's Power Law ($b = 12.55$; $p = -0.178$). An analysis of variance (ANOVA) was carried out and least significant differences (LSDs) computed.

3 Results

3.1 Exploitation of fruit infested with different scale densities

Only a few individual beetles were recorded on the non-infested butternut (Infestation 1, fig. 1). At low through to medium-high prey infestations, increasingly high numbers of beetles accumulated on the butternuts (fig. 1). The ANOVA on the number of *C. nigritus* individuals was highly significant ($F = 175.7$, d. f. $= 5.72$, $P < 0.001$).

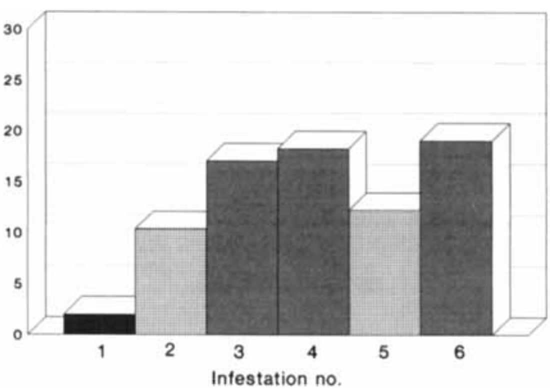

Fig. 1. Mean number of *Chilocorus nigritus* individuals. For visual clarity, each mean is expressed here as a percentage of the sum of means on all infestations. A different pattern denotes a significant difference ($P < 0.001$) between mean beetle numbers. For scale population densities, i.e. infestation no., refer to table 1

At high infestation levels (Infestation 5), where the butternut was not rotting, the density of beetles was significantly lower than those on Infestations 3 and 4 ($P < 0.001$), and similar to that on Infestation 2 (table 2). At still higher infestation levels (Infestation 6), and where the butternut was rotting, the density of beetles was higher than the density on Infestation 5, and similar to that on Infestations 3 and 4 (fig. 1, table 2).

3.2 Ratio of female to male beetles per infestation

The mean ratio of female to male beetles per infestation for non-infested (Infestation 1) and intermediate infestations (Infestations 2, 3 and 4) was 2.18 : 1.0. However, this ratio increased considerably on Infestation 5, only to fall again on Infestation 6 (fig. 2).

4 Discussion

4.1 Oleander scale and red scale equivalence

The low and intermediate Oleander scale levels in table 1 are high compared with red scale on citrus. The presence of two to ten adult scales/cm^2, without drastic countermeasures, would eventually cause a citrus fruit to be so stressed that it would drop off the tree. At this scale level, it would nevertheless take several weeks (as the scale multiplied) which is longer than the approximately monthly generation time of *C. nigritus*. Even at levels above 23.5 scales/cm^2 (see table 1) the fruit may possibly just last a month on the tree. Extrapolating these figures to these Oleander scale experiments involves several equivalences: scale species, vegetable host (citrus versus butternut) and atmospheric conditions (field versus laboratory). This means only rough guidelines can be provided.

Table 2. **Mean (± 1 S.E.) number of *Chilocorus nigritus* individuals per infestation as a percentage of the sum of individuals on all infestations**
Similar letters denote no significant difference between means

Infestation	Mean % number of beetles (± 1 S.E.)
1	1,975 ± 1.05a
2	10,367 ± 1.08b
3	17,032 ± 1.08b
4	18,254 ± 1.06c
5	12,227 ± 1.08b
6	19,022 ± 1.05c

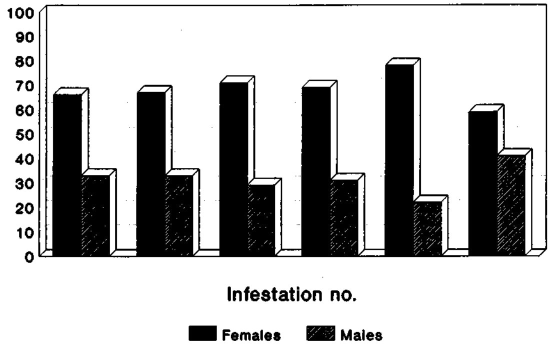

Fig. 2. Percentage ratio of female : male *Chilocorus nigritus* individuals per infestation taken from one replicate

4.2 Predator response to low to medium-high Oleander scale densities

Beetle densities increased with increasing prey scale densities through low to medium-high levels (fig. 1). This is an accumulation effect with beetles gathering on the prey patch with time. It is uncertain whether the beetles are deliberately selecting high densities.

4.3 Predator response to high Oleander scale densities

High scale densities (Infestation 5) supported less beetles than the medium and medium-high densities. Intraspecific interference can be ruled out as a reason for this trend reversal as such interference has been shown to be clearly absent in this coccinellid (Hattingh and Samways 1990). Further, in the field, individuals at certain times of the year readily congregate (Tirumala Rao et. al. 1954; Ketkar 1959).

There is apparently a definite tendency for *C. nigritus* to avoid imminently doomed fruit with high scale levels. Possibly the prey scales are beginning to die off and are increasingly unsuitable prey (Samways 1986). Certainly there would be no adaptive advantage in females ovipositing on such doomed fruit, as the offspring would be insufficiently provisioned. It is unclear why the female : male ratio tends to increase with increasing prey density (table 3, fig. 2). One possibility is that gravid females are able to obtain maximum nutrition for egg development with little expenditure on searching.

Table 3. **Percentage ratio of male : female *Chilocorus nigritus* individuals per infestation**

Counts were taken from one replicate

Infestation	% no of males	% no of females	Ratio
1	34	66	1 : 1.94
2	33	67	1 : 2.03
3	29	71	1 : 2.45
4	31	69	1 : 2.23
5	22	78	1 : 3.55
6	41	59	1 : 1.44

4.4 Predator response to extremely high Oleander scale densities

At this level of scale infestation (Infestation 6) the vegetable host was rotting and predator densities were high. The high predator accumulation on such a deteriorating host is most likely due to the presence of saprophytic fungi, the latter directly or indirectly providing nutrition and moisture. Furthermore, fungal attack may have loosened scale covers allowing easy consumption by the beetles, resulting in less expenditure of energy per scale consumed. Interestingly, the female : male ratio at this prey density was low suggesting perhaps that females avoided dying fruit that would not support offspring.

4.5 Implications for insectary rearing

Medium-high Oleander scale infestations maximizes the production of these coccinellid biocontrol agents in the insectary. Not using overly heavily infested butternuts also lessens the risk of the host vegetable rotting through overexploitation.

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Zusammenfassung

Untersuchungen zur Reaktion des Marienkäfers Chilocorus nigritus (F.) (Col., Coccinellidae) auf faulende Früchte

Chilocorus nigritus ist als Prädator vieler Schildlausarten bekannt und stellt in den subtropischen Zitrusplantagen Südafrikas einen wirtschaftlich wichtigen natürlichen Feind der Roten Zitrusschildlaus, *Aonidiella aurantii* (Maskell) dar. Obwohl diese Marienkäferart leicht in Massenzucht genommen werden kann und auch die Freisetzung kein Problem ist, so gab es dennoch Vermutungen, daß *C. nigritus* nicht auf Früchten frißt, die einen sehr hohen Schildlausbefall aufweisen. Versuche mit der Alternativbeute *Aspidiotus nerii* Bouché ergaben, daß niedrige bis mittelhohe Schildlauspopulationen förderlich für eine hohe Marienkäferdichte waren. Bei hoher Schildlausdichte, bei der eine baldige Fruchtfäule drohte, zeigte sich bei den Käfern ein deutlicher Dichterückgang. Bei noch höherer Schildlausdichte, die bereits dazu geführt hatte, daß die Früchte zu faulen begannen, zeigte sich bei den Käfern wieder ein Dichteanstieg, der jener bei mittelhoher Schildlausdichte entsprach. Bei niedriger bis mittelhoher Wirtsdichte wurden männliche und weibliche Käfer zu ungefähr gleichen Teilen gefunden. Bei hoher Wirtsdichte, die eine baldige Fruchtfäule zur Folge hatte, zeigte sich eine Tendenz zugunsten der Männchen, die bei noch höherer Wirtsdichte ganz deutlich war. Es scheint bei *C. nigritus* ein Mechanismus zu existieren, der bewirkt, daß Früchte, kurz bevor sie zu faulen beginnen, gemieden werden. Dagegen weisen faulende Früchte eine Attraktivität, jedoch mehr für die Männchen, auf. Eine kommerzielle Massenzucht von *C. nigritus* kann bei mittelhoher Schildlausdichte die besten Ergebnisse erzielen.

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