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Consumption, developmental and reproductive attributes of two con-generic ladybird predators under variable prey supply

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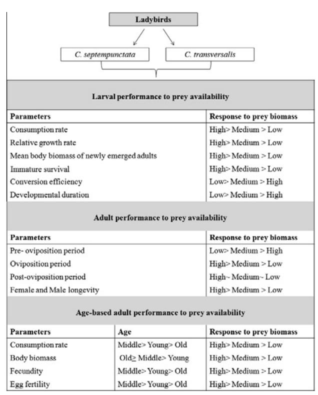
HIGHLIGHTS

- Evaluated performance of two con-generic ladybirds on three prey biomasses.
- Larvae developed fastest and survived maximum on high prey biomass.
- Middle aged adults consumed and reproduced maximally on high prey biomass.
- Females consume prey to increase body biomass at early & late reproductive phases.
- Females invest more on oviposition during their reproductive phase.

GRAPHICAL ABSTRACT



Larval performance to prey availability	
Parameters	**Response to prey biomass**
Consumption rate	High> Medium > Low
Relative growth rate	High> Medium > Low
Mean body biomass of newly emerged adults	High> Medium > Low
Immature survival	High> Medium > Low
Conversion efficiency	Low> Medium > High
Developmental duration	Low> Medium > High

Adult performance to prey availability	
Parameters	**Response to prey biomass**
Pre- oviposition period	Low> Medium > High
Oviposition period	High> Medium > Low
Post-oviposition period	High~ Medium~ Low
Female and Male longevity	High> Medium > Low

Age-based adult performance to prey availability		
Parameters	**Age**	**Response to prey biomass**
Consumption rate	Middle> Young> Old	High> Medium > Low
Body biomass	Old≥ Middle> Young	High> Medium > Low
Fecundity	Middle> Young> Old	High> Medium > Low
Egg fertility	Middle> Young> Old	High> Medium > Low

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ABSTRACT

Availability of aphid prey in habitat is often heterogeneous in space and time and its deprivation causes severe effects on life attributes of ladybird predators. Sometimes ladybirds locate high prey biomass while on certain occasions prey biomass may be either medium/low or altogether absent. Present study has been designed in view of three prey biomass conditions in nature, *viz.* low, medium and high, selecting *Coccinella septempunctata* and *Coccinella transversalis* as experimental ladybirds. Results revealed that consumption, developmental and reproductive attributes of both ladybirds changed in response to prey availability. On high prey biomass larvae had higher consumption and growth rates, developed faster and had low mortality, while emerging adults were large in size, had high consumption rates and utilized prey biomass maximally on production of eggs, self maintenance and survival. In contrast low prey biomass reduced chances of larval survival and emerging adults were small in size, had poor prey consumption rates, low fecundity, egg fertility and short life span. Females exhibited triangular fecundity and egg fertility functions and plateau shaped prey consumption rate function with age, indicating towards their highest reproductive performance during middle age on three prey biomasses; being highest on high prey biomass. On three prey biomasses, females had higher body biomass conversion efficiency during pre- and post-oviposition periods and higher egg biomass conversion efficiency during oviposition period; being highest on high prey biomass. Thus middle aged ladybirds reared on high prey biomass may suppress pest populations better than those reared on low/medium prey biomass.

1. Introduction

Prey availability is often heterogeneous in space and time and its deprivation causes severe effects on the life attributes of

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ladybirds (Phoofolo et al., 2008; Santos-Cividanes et al., 2011) which forage in unstable habitats with variable prey density (Agarwala et al., 2001). Studies have shown that reduced prey consumption (Phoofolo et al., 2008) and/or prey deprivation severely affect the development and survival of ladybirds (Omkar and Pervez, 2003; Schuder et al., 2004; Atlihan and Guldal, 2009), and the developmental rate and the size of offspring (Agarwala et al., 2001; Seagraves, 2009). Under limited prey conditions the larvae develop slowly and the surviving adults are smaller in size. Further prey deprivation negatively affects the reproductive attributes of ladybirds (Dmitriew and Rowe, 2011). Under prey deprived conditions the pre-reproductive periods of adults are considerably prolonged and their reproductive phase, fecundity (Agarwala et al., 2008, 2009), oviposition rate and clutch size are highly reduced (Dixon, 2000; Ware et al., 2008).

It therefore appears that there is a strong selection pressure in the natural populations of ladybird predators for survival, reproduction and offspring performance under limited prey resource. Moreover, the prey abundance/ deprivation not only affect the parents but also have trans-generational effects (Omkar et al., 2010); and the individuals that acquire abundant resource transfer their resources to offspring and enhance offspring fitness (Qvarnström and Price, 2001; Bonduriansky and Head, 2007).

There are a few studies that have evaluated the stage and age specific consumption attributes in larval and/or adult stages (Schuder et al., 2004; Mishra et al., 2012), but not much work has been done on the comparative consumption and reproductive attributes of ladybirds under high prey/ low prey biomass conditions. The present study has been aimed to: (i) assess the impact of prey quantity (low, medium and high biomass) on the larval consumption (consumption rate, conversion efficiency and/or relative growth rate) and immature development of two congeneric ladybirds, viz. *Coccinella septempunctata* (L.) and *Coccinella transversalis* F., (ii) evaluate their reproductive attributes under variable prey quantities, (iii) understand how these ladybirds compensate for the reduction in prey supply in terms of consumption, survival and reproduction, and (iv) facilitate the mass multiplication of these ladybirds for the augmentative biocontrol of aphid pests.

C. septempunctata, though of Palearctic origin, is ubiquitous owing to its euryphagous nature, is large in size and has wide adaptability to different climatic conditions and food habitats (Hodek and Michaud, 2008). On the other hand *C. transversalis* is another large sized aphidophagous ladybird of Oriental region, native to India and found conspicuously in South Asia (Omkar et al., 2005a). Both the ladybirds co-exist as predators of numerous aphid species that infest the local agricultural crops of India. Because of wide prey range and association with a variety of aphid species, both ladybirds are recognized as effective biocontrol agents in the aphid management program.

2. Materials and methods

2.1. Stock maintenance

Adults of *C. septempunctata* (C7) and *C. transversalis* (Ct) ($n = 40$) were collected from the fields of Lucknow, India (26°50′N, 80°54′E), paired and reared in plastic Petri dishes ($14.5 \times 1.5\ cm^2$) under constant abiotic conditions (27 ± 2 °C; 65 ± 5% RH; 14L:10D photoperiod) in Environmental Test Chambers (ETC.; CH-6S Remi Instruments, Mumbai, India). They were provided with *ad libitum* aphid, *Aphis craccivora* Koch infested on cowpea (*Vicia faba* Linnaeus; Fabaceae) plants maintained in polyhouse (28 ± 1 °C; 65 ± 5% RH and 14L:10D photoperiod). The eggs laid were collected every 24 h, observed for hatching and the neonates obtained were used in the experiment.

2.2. Experimental design

2.2.1. Effect on consumption and developmental attributes

Neonates of both the ladybird predators were weighed 12 h after hatching using an electronic balance (Sartorius CP225-D; 0.01 mg precision) and kept individually in plastic Petri dishes (abiotic conditions similar to stock). They were reared on any one of the following diets throughout their development (i.e. first instar to adult emergence), *viz.* (i) low prey condition (25 mg ∼ 60 third instars of *A. craccivora*), (ii) medium prey condition (50 mg ∼ 120 third instars of *A. craccivora*), and (iii) high prey condition (75 mg ∼ 180 third instars of *A. craccivora*).

Prior to experimentation, prey biomasses (low, medium and high) were standardized on the prey consumption ability of: (i) late third/early fourth instars of C7 and Ct (most voracious stages amongst larvae and their prey consumption ability directly influence the adult reproductive performance; Mishra et al., 2012; Michaud, 2000, 2005), and (ii) 8–12 day old females (at this age females of C7 and Ct are highly voracious; Mishra et al., 2012). When fed on low prey, no aphid was left after 24 h. Under medium prey condition, larvae/females left scanty aphid biomass (2.00 ± 1.0 mg) in Petri dishes and under high prey supply, larvae/ females left surplus aphid biomass (8.00 ± 2.00 mg) after 24 h.

The larvae were separated from the remaining biomass of prey (consisting of live and dead aphids as well as aphid parts and faecal matter) every 24 h and the remaining biomass was measured before providing a fresh amount to the larvae. Also the Petri dishes were examined every 24 h for the presence of larval moults (indicative of the next developmental stage), and once the moults were detected the biomass of larvae was measured. The durations of different immature stages were recorded on each prey quantity. The numbers of larvae surviving on each prey quantity were also recorded. The observations were made once daily, i.e. at 24 h interval.

A mortality life table was constructed according to Morris and Miller (1954), where:

(i) x is the developmental stage, i.e. all four larval instars, prepupae, pupae and adults;
(ii) lx is the number of individuals entering the stage x;
(iii) dx is the number of individuals dying within the stage x;
(iv) 100qx is the apparent mortality, dx as a percentage of lx;
(v) 100rx is the real mortality, dx as a percentage of the original cohort size;
(vi) *k*-Value is a dimensionless measure of the mortality within the age interval x, calculated as the difference between the log values of the number of surviving individuals in subsequent stages;
(vii) Sx is the survival rate of a stage, calculated from the number of individuals surviving the present stage number versus the number in the previous stage;
(viii) K (kappa) is the sum of *k*-values;
(ix) Mortality: survivor ratio (MSR). This shows the increase in the population that would have occurred if the mortality in the particular stage (x) had not occurred. This was calculated for a particular stage as: MSR = [mortality in the particular stage/lx of subsequent stage];
(x) Indispensable mortality (IM). The mortality that would not occur in a population, if the factor causing it is not allowed to operate and was calculated as: IM = [total number of adults emerged] × [MSR of the particular stage].

Sex ratio was calculated as the ratio of the total number of females to the total number of adults (Omkar et al., 2009), while generation survival was calculated as the ratio of number of females to the number of first instars (modified after Harcourt,