

## Research Article

## Feeding and fecundity in the predator, *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae)

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**ABSTRACT:** The relationship of food consumption during the grub stage with the subsequent adult stage of female *Cryptolaemus montrouzieri* (Coleoptera: Coccinellidae), and the impact of food consumption on its fecundity was studied. Food consumption of the adult female *C. montrouzieri* was found to be positively correlated with food consumption during the grub stage and the regression analysis explained 54% of the variability ( $y = 0.3418x + 1.3884$ ;  $R^2 = 0.542$ ). Further, fecundity was found to be linked to the adult female's food consumption with a highly significant positive correlation to consumption of previous 1st day ( $r = 0.83$ ), 2nd day ( $r = 0.82$ ), 3rd day ( $r = 0.81$ ), 1st + 2nd day ( $r = 0.83$ ), 2nd + 3rd day ( $r = 0.82$ ) as well as to cumulative food consumption ( $r = 0.83$ ). Linear and non-linear functions explained the relationship between amount of food consumed and numbers of eggs laid to the extent of 85% ( $y = 1.6075x + 46.8$ ;  $R^2 = 0.8456$ ) and 89% ( $y = 15.198x^{0.5681}$ ;  $R^2 = 0.8854$ ), respectively. Thus, selection for high food consumption in the grub stage also selects indirectly *C. montrouzieri* adult females that lay copious quantities of eggs..

**KEY WORDS:** *Cryptolaemus montrouzieri*, feeding, fecundity, life stages.

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### INTRODUCTION

Feeding and fecundity are the important life-history traits of an effective predator. In holometabolus insects, the feeding habit of adult stage usually differs from that of the immature stages with few exceptions like the predatory coccinellid, *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae) where both the grub and adult feed on all developmental stages of the prey viz., mealybugs; thus exhibiting similar dietary breadth. Such similar feeding habits of juvenile and adult stages have the advantage of bringing down the target prey population with in short span that makes this predator ideal for use in biocontrol programs (Dixon, 2000). This predatory coccinellid is quite often recommended by pest managers to manage various species of mealybugs (Bartlett 1978; Babu and Azam 1987; Mani and Krishnamoorthy 1998; Ozgokce *et al.*, 2006; Samira *et al.*, 2011). However, currently in mass rearing programs, the key attributes of an effective natural enemy, viz., feeding (functional response) and fecundity (numerical response)

are not being given proper attention during the progeny development. The nature and extent of influence that the juvenile stage can exercise on the life-history traits of their prospective adult stage is not fully understood.

Therefore, it is imperative to study the feeding potential of predators in relation to their juvenile stage, to understand this trait trade-off between the grub and adult stage particularly in *C. montrouzieri* where both the stages feed upon similar prey as mentioned earlier. Several studies carried out to date were mainly focussed on phytophagous insects and explained the relative influence of prior life stages on the adult stage preference/non-preference (Dethier 1954; Jaenike 1983; Corbet 1985; Schoonhoven *et al.*, 1998). These studies emphasize the importance of larval experience in shaping the adult feeding preference (Barron 2001) without being genetically fixed. However, the feeding preference in the granary weevil, *Sitophilus granarius* L. (Coleoptera: Curculionidae) was observed to be shaped by a combination of larval experience (according to the Hop-

kins host-selection principle), early adult experience (of the neo-Hopkins principle) and possibly genetic predisposition (Katja and Johannes, 2002). Similarly, the influence of a predator's previous experience on its subsequent prey preference suggesting a kind of 'food imprinting' was reported in *C. montrouzieri* (Begon *et al.*, 1996; Kamala Jayanthi *et al.*, 2010). All these studies carried out either on phytophagous or predatory insects aimed to explain the choice or preference of the adult insect based on its juvenile stage. However, till to date no comparative studies to understand the quantitative utilization of prey between the grub and adult stages of *C. montrouzieri* were carried out.

Another important attribute of a successful predator is its fecundity and was studied exclusively in several insect species. Previous studies explained the fecundity in predatory insects as a function of diet (Bjorn *et al.*, 2006). The positive role of increased adult feeding in enhancing fecundity was observed in *Helicoverpa armigera* (Lepidoptera: Noctuidae) (Zeng *et al.*, 2007). Similar increase in fecundity with increased prey density was also noticed in the mantis *Paratenodera angustipennis* (S.) (Mantodea: Mantidae) (Toshiaki and Kiyomi 1983). Although adult feeding significantly affects the reproduction (Alexandre *et al.*, 2010), there is no data on *C. montrouzieri* to understand the exact influence of juvenile *vis a vis* respective adult feeding, on its fecundity. Here, our goals were to study whether the feeding potential of adult *C. montrouzieri* is akin to that of its grub stage?, and secondly, to examine whether the voracious female beetles are good egg layers too?. For these studies the prey insect selected was pink hibiscus mealybug, *Maconellicoccus hirsutus* Green (Homoptera: Pseudococcidae), a highly polyphagous pest of several agriculturally important crops (Reddy *et al.*, 2009).

## MATERIALS AND METHODS

### Test insects

The *C. montrouzieri* samples used for the present study were collected from the established mass culture at Indian Institute of Horticultural Research, Bangalore (12°58'; 77° 35'E), India. The original culture for the experiment was obtained from National Bureau of Agricultural Insect Resources, Bangalore, India (National Accession No. NBAIL-MP-COC-01). The *C. montrouzeiri* culture used for the study was further maintained continuously for 10 generations on pink hibiscus mealybugs (*Maconellicoccus hirsutus*) reared on round yellow pumpkins (*Cucurbita moschata* Duchesne ex Poir.; Cucurbitales: Cucurbitaceae) (Kairo *et al.*, 1997). All the insects were maintained under ambient room conditions (at 28±1°C under the natural light phase) and experiments were also carried out under similar conditions.

## Experiments

The freshly laid eggs (150) of *C. montrouzieri* were randomly selected from the established laboratory cultures and kept for hatching separately in petri plates. Immediately after hatching, each grub was placed in an independent 9 cm-diameter petri dish (approximately 64 cm<sup>2</sup>) lined with 90 mm-diameter Whatman filter paper. Each grub was provided daily with a fixed number (10) of adult mealybugs, *M. hirsutus*. Observations were made on the number of mealybugs consumed each day by the grub and the observations were continued up to pupation (~15 days). After emergence of the adult beetle, feeding observations were continued by providing a fixed number (10) of adult *M. hirsutus* daily and observations were made on the number of the mealybugs consumed by the each adult beetle for 15 days.

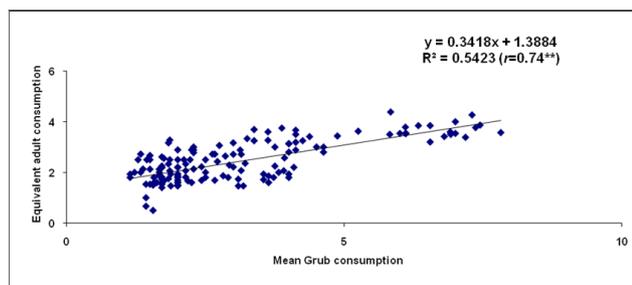
To study the influence of feeding on egg laying, 25 adult female beetles were kept together with equal number of males immediately after eclosion for one week to allow mating. After one week the mated female beetles were separated and kept individually in a 9 cm-diameter petri dish (approximately 64 cm<sup>2</sup>) lined with 90 mm-diameter Whatman filter paper. Each beetle was provided daily with a fixed number (10) of uniform sized adult mealybugs, and observations were made continuously for 15 days on the number of mealybugs consumed and the number of eggs laid by each female beetle. The data from the above experiments were subjected to ANOVA, paired *t*-test, correlation, linear and nonlinear analyses (Little and Hills 1978).

## RESULTS AND DISCUSSION

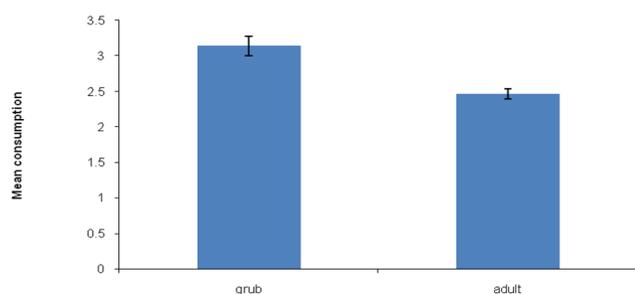
### Good grubs were found to be good adults too

Feeding efficiency of the adults was found to be akin to their respective grubs. A highly significant positive correlation ( $r = 0.74^{**}$ ) was found between the food consumption of the grubs and their respective eclosed adults. The linear regression analysis showed that significant variability (up to 54%) in the mean prey consumption ( $F$  ratio: 169.46,  $P < 0.0001$ , df, 143) of adult beetles could be attributed to their grub stage ( $y = 0.3418x + 1.3884$ ;  $R^2 = 0.5423$ ) (Fig. 1). Thus the consumption efficiency/ predation efficiency of an adult beetle was similar to its grub stage. This clearly endorses that good grubs will necessarily translate into good adults in terms of feeding efficiency. Plotting the residuals of observed and estimated adult feeding efficiencies using the feeding efficiency of the respective juvenile stage as an independent variable, showed a random dispersal of points across the X-axis explaining the good-fit of the linear function. Though there was a significant difference between the feeding efficiencies of grub (3.14 mealybugs/day) and adult (2.46 mealybugs/day) ( $n = 144$ ,  $t$  value, 6.53;  $P < 0.0001\%$ )

(Fig. 2). Feeding efficiency of adults was found to be proportional to the feeding efficiency displayed during their respective grub stages.



**Fig. 1.** Relationship between mean food consumption of female *C. montrouzieri* individuals during the grub and their subsequent adult stages.



**Fig. 2.** Mean numbers of *M. hirsutus* adult mealybugs consumed by female *C. montrouzieri* grubs and their subsequent adult stages.

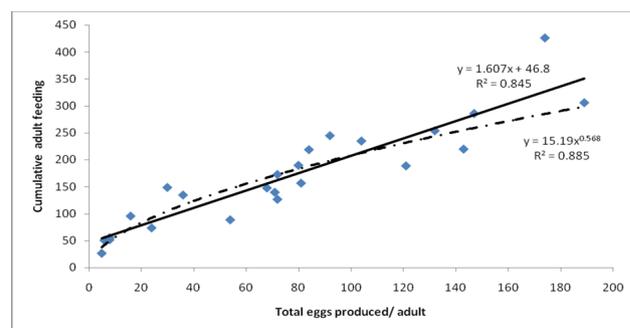
### Voracious *C. montrouzieri* females are good egg layers too

There was a high significant positive correlation between food consumption and egg laying in *C. montrouzieri*. The number of eggs laid by an adult female *C. montrouzieri* was found to be significantly correlated to its food consumption on the previous 1st day ( $r = 0.83^{**}$ ), 2nd day ( $r = 0.82^{**}$ ), 3rd day ( $r = 0.81^{**}$ ), 1st + 2nd day ( $r = 0.83^{**}$ ), 2nd + 3rd ( $r = 0.82^{**}$ ) day as well as to their total cumulative food consumption ( $r = 0.83^{**}$ ) (Table 1). The food consumption of adult female *C. montrouzieri* was found to be proportional to their egg laying. This clearly shows that selection of good feeders automatically selects good egg layers too. The scatter plot between the cumulative food consumption and numbers of eggs laid by adult female *C. montrouzieri* beetles explained the significant variability (up to 89%;  $F$  ratio: 120.48;  $P < 0.0001$ ) in the egg laying by cumulative feeding through the power function ( $y = 15.198x^{0.5681}$ ;  $R^2 = 0.8854$ ) and up to 85% variability through linear function ( $y = 1.6075x + 46.8$ ;  $R^2 = 0.8456$ ) (Fig. 3).

**Table 1.** Relationship between food consumption and oviposition in female *Cryptolaemus montrouzieri* females

Adult Feeding	Total egg production ( $r^2$ )
3rd day feeding(previous)	0.81**
2nd day feeding (previous)	0.82**
1st day feeding (previous)	0.83**
Zero day feeding	-
2nd +1st day feeding	0.83**
3rd +2nd day feeding	0.82**
Cumulative	0.83**

\*\* significant @ 1%



**Fig. 3.** Scatter plot showing relationship between cumulative food consumption and total numbers of eggs laid by *C. montrouzieri* adult females.

A highly significant positive correlation was observed between food consumption of the grub and that of the adult explaining that the ability to feed is an inherent trait of a particular individual, which suggests that the feeding potential of *C. montrouzieri* may be partially under genetic control as variability in the food consumption of an adult female was explained to the extent of 54% by her food consumption during grub stage. Previous studies also reported a genetic influence on the foraging-related activities such as food-related locomotion, food intake, responses to food deprivation, energy homeostasis, sucrose responsiveness and learning in *D. melanogaster* (Belay *et al.*, 2007). However, a significant difference between the *C. montrouzieri* grub and adult feeding was observed in the present study as the grubs of *C. montrouzieri* were found to be more voracious feeders than the adults for the period under study. Similar results that late grub stages were found to be more voracious compared to other stages was earlier reported (Mani and Thontadarya 1987; Baskaran *et al.*, 1999; Lucas *et al.*, 2004). Similarly, changes in adult feeding were noticed during early, mid and late stages of their life cycle

(Kamala Jayanthi *et al.*, 2014). Nevertheless, the extremely long life span of *C. montrouzieri* adult females (~52 to 120.8 days) imparts a predaceous advantage to adult on the temporal scale compared to that of short spanned immature stages (Mani and Krishnamoorthy 1997; Al-Khateeb and Raie 2001; Persad and Khan 2002; Ozgokce *et al.*, 2006).

In the present study, a very high significant positive relationship was observed between all previous days of food consumption (previous 1st, 2nd, 3rd, 1st + 2nd, and 2nd + 3rd days), cumulative feeding and fecundity clearly indicating that the voracious female feeders were good egg layers also. The aphidophagous coccinellids, *M. sexmaculatus* Fab. and *Harmonia axydiris* (Pallas) exhibited similar prey consumption related egg functions where peak egg production coincided with the peak aphid consumption (Dixon and Agarwala 2002). Similar diet related influence on fecundity is also observed with the predatory pentatomid, *Podisus maculiventris* (Say) where nymphal and adult stage diets influenced the formation of previtellogenic follicles and vitellogenesis respectively (Wittmeyer *et al.*, 2001; Wittmeyer and Coudron 2001). The diet dependent fecundity increase was also observed in another heteropteran polyphagous predator, *Macrolophus caliginosus* where females fed on eggs laid more eggs than those fed on artificial diet or those given no extra food (Bjorn *et al.*, 2006).

Both linear and non-linear (-power) functions explained the relationship between feeding and egg laying in adult *C. montrouzieri* satisfactorily. Interestingly, here both the functions could accurately model the situation, though power function explained the maximum variability in the egg laying of the adult *C. montrouzieri* due to food consumption. Usually the power function fits well to the data where rate of increase or decrease is proportional to the base values as observed in the present study in which the increase in fecundity was proportional to the increased food consumption of *C. montrouzieri* adult females.

The present study clearly showed that the prey consumption by the adult female *C. montrouzieri* is proportional to that of feeding rate previously displayed during the respective grub stage indicating that the feeding potential in this predatory coccinellid may be inherent with partial genetic predisposition. Further, we found that the fecundity of the *C. montrouzieri* female is linked to her food consumption. In other words, selection for voracious feeders in the grub stage will help indirectly to select good egg laying adults later. Usually, reproduction of the most insects depends on nutrients accumulated during the juvenile stage (Alexandre *et al.*, 2010). Thus, in mass rearing programs of *C. montrouzieri*, careful selection of aggressive grub

stages as founding stock and culling of weak grubs ensure production of voracious progenies with copious egg laying capabilities.

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