Does food adaptation influence prey choice of a generalist predator, *Cryptolaemus montrouzieri* Mulsant?

Many coccinellids, popularly referred to as ladybird beetles (family Coccinellidae, order Coleoptera), are generalist predators on various insects like mealybugs, scales, aphids, mites and whiteflies[1,2]. This wide range of dietary breadth benefits them in naturally sustaining ecosystems by switching to a different prey altogether, in situations when one food source falls short. Generalist coccinellid predators such as *Cryptolaemus montrouzieri* Mulsant (hereafter *Cryptolaemus*) are frequently released in large numbers in the fields after continuous laboratory rearing on a particular prey and the immediate prey specificity/ preference is not always looked into prior to their field release. If such dietary specificity exists in *Cryptolaemus* (?), it presents a challenge for classical biological control programmes involving coccinellids, where the laboratory cultures are continuously bred for generations on specific prey (conditioned/trained) before their target release in the field. On the other hand, the interaction between *Cryptolaemus* and the target prey should be predictable in the new habitat, and has important implications for the stability of predator–prey dynamics[3]. Given the broad range of variability in the dietary breadth of generalist predator, *Cryptolaemus*, its preference among the available field dietary resources, is all the more important as biological control efforts would benefit greatly from detailed studies on how the pre-conditioned preference of a particular predator will change with continuous learning/ exposure to a new prey and with physiological limitations like starvation. Therefore, the present study was carried out to know whether pre-conditioning of a generalist predator on a particular prey affects the way it forages when it encounters an altogether different prey.

Laboratory studies were conducted at the Indian Institute of Horticultural Research (IIHR), Bangalore (12°58′N; 77°35′E), Karnataka, India. The laboratory cultures of *Cryptolaemus* that were continuously maintained for 10 generations on pink hibiscus mealybug, *Maconellicoccus hirsutus* Green (Pseudococcidae: Heteroptera) were used for the current study.

Three different sets ($n = 30$) of *Cryptolaemus* from this established culture were exposed to three different preys, viz. field-collected *Rastrococcus iceryoides* Green (Pseudococcidae: Heteroptera) on mango, *Mangifera indica* L. and *Phenococcus solenopsis* Tinsley (Pseudococcidae: Heteroptera) on congress weed, *Parthenium hysterophorus* L., to study the changes in immediate prey preference along with regular prey, *M. hirsutus* for comparison. In each set, 10 (prestarved for 12 h) late second-instar grubs were kept individually in separate petri plates and provided with a fixed number of respective second-instar mealybugs as prey. Observations on the number of mealybugs consumed were recorded every 12 h. The experiment was continued with the same grubs and terminated when 50% of them pupated. After emergence, again the respective adults were given the same food on which they were fed during their grub stage. Thus, the prey-preference studies were carried out through larval and adult stages (continuously for 47 days) with brief and rigorous starvation in between, to study any change in their preference towards each species separately. The data were subjected to analysis of variance (ANOVA) and linear/nonlinear analyses[4].

On day-one of the experimentation, the predator consumed significantly more number of *M. hirsutus*, showing that *Cryptolaemus* had clear preference (8.60, 3.60, 1.00 mealybugs^{-1} of *M. hirsutus*, *P. solenopsis* and *R. iceryoides* respectively; $P \leq 0.05$) for *M. hirsutus*, i.e. on which it was being reared continuously prior to the study (Table 1). A similar trend was observed till pupation indicating that previous experience of a predator (adaptation/conditioning/learning) can influence its prey preference subsequently[3], suggesting 'food imprinting' in this generalist predator *Cryptolaemus*. This food imprinting or 'preconditioned prey specificity' has practical implications, particularly in case of the generalist predator, *Cryptolaemus* that is being used on a commercial scale in the field to control several mealybug species. Usually the grub stage of *Cryptolaemus* is shipped and released. In such situations, if the released coccinellid grubs were reared on species other than the target mealybug species, they may take a certain amount of time initially to start liking/accepting the available prey (six days as in the present study), and therefore it may not be practical when quicker control is expected. Further, the suppliers also must bear in mind to rear the predator culture according to the species targeted, which will be immediately accustomed to the target prey in the field in continuum, or at least the predators should be conditioned/trained to the target prey (on which it is going to feed in the field) for a short period while switching to the new preys (i.e. different from the prey used for culturing) for achieving better results. This was clearly established in the present study, where during the training period a slow and steady increase in the feeding ability of *Cryptolaemus* was observed from day-one to day-five, with significant positive correlation between feeding and training ($r = 0.67$). Here, variability in feeding to the tune of 46% can be attributed to training alone ($y = 0.41x + 2.71$; $R^2 = 0.4578$). Therefore, this 'conditioning' serves as a customary type of learning and may bring about changes in feeding preferences.

After emergence, there was no significant difference in the weight of the adults that were reared on three species of mealybugs (0.0604 g^{-1}, 0.0601 g^{-1} and 0.0574 g^{-1} in case of *P. solenopsis*, *M. hirsutus* and *R. iceryoides* respectively; $P \leq 0.05\%$). However, mortality to the tune of 50% was observed immediately, on the second day after emergence in the case of *Cryptolaemus* fed on *R. iceryoides*. Whereas *Cryptolaemus* fed on *P. solenopsis* and *M. hirsutus* recorded 30% and 40% mortality only on the 47th day of experimentation, i.e. 27 days after emergence.

Interestingly, after emergence the adult *Cryptolaemus* preferences were akin to its previous prey preferences exhibited during the respective grub stages, indicating again that a form of food-imprinting may be operative in this generalist predator. Though weak preference was observed for both *M. hirsutus* and *R. iceryoides*, the adult coccinellids (first two days after emergence) continued to

Table 1. Prey preference of *Cryptolaemus* (grub and adult) for different mealybug species before pupation

Prey type	Mean mealybug consumption^{-1}					
	Days after experimentation					
Grub	1	3	4	5	6	
Phenococcus solenopsis	3.60	3.70	2.80	4.20	5.40	
Rastrococcus iceryoides	1.00	4.60	2.70	2.20	4.40	
Maconellicoccus hirsutus	8.60	10.00	8.70	7.40	7.60	
CD (P = 0.05)	1.26	1.50	1.76	2.46	2.28	
Adult	21	22	24	25	26	27
P. solenopsis	5.60	3.80	5.60	4.40	5.10	4.30
R. iceryoides	7.80	7.60	5.40	5.20	6.20	5.60
M. hirsutus	6.80	7.20	6.30	6.00	5.80	5.20
CD (P = 0.05)	1.84	1.73	NS	NS	0.81	0.89

NS, Non-significant.

Table 2. Prey preference of *Cryptolaemus* (adult) for different mealybug species after starvation

Prey type	Days after experimentation							
	39	40	41	42	43	44	46	47
*Phenococcus solenopsis**	6.60	5.80	5.30	3.90	3.80	3.50	4.11	3.17
*Rastrococcus iceryoides***	4.00	4.40	4.40	4.00	3.00	3.20	5.40	4.20
*Maconellicoccus hirsutus***	4.00	4.20	3.20	3.20	3.60	4.70	6.20	6.50
CD (P = 0.05)	1.39	1.50	1.12	NS	NS	1.23	1.83	0.95

*Rigorous starvation was given for 12 days; **Brief starvation was given for 4 days; NS, Non-significant.

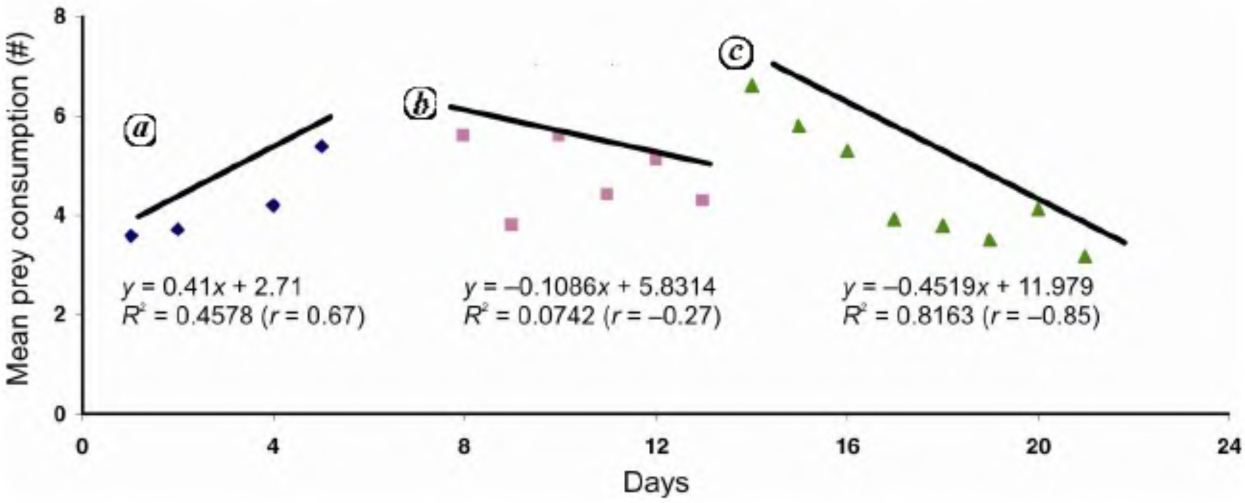

Figure 1. Feeding trend of *Cryptolaemus* on *Phenococcus solenopsis* during different phases: ***a***, Training (grab) (n = 40); ***b***, After emergence (adult) (n = 60), and ***c***, After starvation (adult) (n = 80).

be averse towards *P. solenopsis*, as they were during the grub stage (6.80, 5.60, 7.80 mealybug^{-1} of *M. hirsutus*, *P. solenopsis* and *R. iceryoides* respectively; $P \leq 0.05$). In contrast to the earlier situation of 'training', the correlation between the mean consumption and days was found to be negative (–0.27). Similarly, the trend line ($y = -0.1086x + 5.8314$, $R^2 = 0.0742$) also exhibited negative trend (Figure 1). After two days there was no significant difference in prey consumption (Table 1). This again endorses the above presumption that 'brief conditioning' will always help to tune a generalist predator like *Cryptolaemus* towards its target prey.

To study whether subjecting a predator to physiological stress like starvation can alter its preference, particularly when a predator had a weak preference as in the case of *P. solenopsis*, rigorous starvation for 12 days was given for *Cryptolaemus* adults that were feeding on *P. solenopsis*. Interestingly, a 'reversal prey specificity' was observed on the 39th day of experimentation, where high prey consumption was recorded in *P. solenopsis* compared to the others (Table 2). However, this did not last long and again the aversion to *P. solenopsis* was evident within a day. This was further supported by regression [$y = -0.4519x + 11.979$, $R^2 = 0.8163$ ($r = -0.85$)] to the tune of 81% (Figure 1). This indicates that weak preference of a predator to a particular prey cannot be altered by subjecting the predator to stress, and the reversal prey specificity exhibited only for a short period can be referred to as 'transient reversal prey specificity'. Thus, contrary to common assumptions, *Cryptolaemus*, a generalist is conspicuously selective in its diet. Although there is a possibility that conditioning/training/starvation over a period of time, i.e. as a consequence of previous exposure may alter predator–prey preference. Nonetheless, its choice seems to be almost fixed and maintained irrespective of relative availability of the prey, as seen in the present study. However, seasonal availability of prey, microclimatic conditions and competition can also be a major determinant of prey specificity[5] and may form an altogether different area of study. Such studies will be necessary in the near future and biological control efforts would benefit greatly from detailed studies of predator–prey interactions.

Given the broad range of variability in the diet breadth of predacious coccinellid, *C. montrouzieri*, the present study indicated that recommending this predator in the field should always be considered with brief pre-conditioning towards the target prey prior to its release, as it may help in reversal prey specificity. Further, situation-specific, species-specific prey preference of *Cryptolaemus* has to be studied, since even conditioned response of reversal prey specificity could not last long as in the case of *P. solenopsis*. Thus recommending *C. montrouzieri* should always go with a note of caution.

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