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Fitness trade-offs in parasitoid-host system: with special reference to *Acerophagus papayae* noyes on papaya mealybug, *Paracoccus marginatus* williams and granara de willink

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ABSTRACT

Development and parasitic potential of *Acerophagus papayae* Noyes on the papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink from different host plants like papaya, cotton, mulberry, tapioca, brinjal and hibiscus were studied. The development time of parasitoid, *A. papayae* in the current study was shortest in mealybugs reared from papaya (10.9 days), followed by cotton (11.8 days), mulberry (12.4 days), brinjal (13.1 days), hibiscus (14.1 days) and recorded 16.3 days of development in tapioca reared papaya mealybug. The parasitisation rate was found to be highest in second instar than third instar and adult female mealybugs from host crop papaya *viz*., 87.5 per cent followed by cotton (84.2 %), mulberry (80.8 %), brinjal (80.0 %) and potato sprouts (75.8 %) and recorded lowest parasitisation rate in tapioca (67.5%). The parasitization level of parasitoid, *A. papayae* was maximum in papaya and minimum in tapioca due to the host plant induced changes in the mealybug. The development time was inversely correlated with the parasitic potential and so there was a trade-off between the development and parasitic potential of parasitoid.

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INTRODUCTION

The papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae) is a small polyphagous sucking pest that attacks several genera of host plants like hibiscus, mulberry, eggplant, castor, teak, pigeonpea, tapioca, jatropha and many weed hosts, including parthenium and causes severe yield losses. It also invades economically important crops like tropical fruits, vegetables and ornamentals. *Acerophagus papayae* Noyes (Encyrtidae) is one of the efficient parasitoids for the suppression of papaya mealybug in Central America. (Miller *et al.*, 1999). This species was first described by Williams and Granara de Willink in 1992 from the specimens collected from neo-tropical regions in Belize, Costa Rica, Guatemala and Mexico (Williams and Granara de Willink, 1992). In 2002, Miller and Miller re-described this mealybug species (Miller and Miller, 2002). Infestations of papaya mealybug have been observed on papaya, plumeria, hibiscus and jatropha in Hawaii with the favoured hosts appearing to be papaya, plumeria, and hibiscus (Heu *et al.*, 2007). However, insects may settle, lay eggs, and severely damage plant species that are unsuitable for development of immatures (Harris, 1990).

This parasitoid was introduced in India with the help of USDA by the National Bureau of Agriculturally Important Insects, (NBAII), Bangalore during 2010 (Pokharkar *et al*., 2010). Although remarkanble success has been achieved in managing papaya mealybug in South India by the parasitoid in certain crops, the efficiency of the later varied in different crop ecosystem. The reason could be either co-evolution of host insect against the parasitoid or adaptive plasticity of parasitoid on mealybugs in different crops ecosystem. In this context, the present investigatins were made to deduct, if there is any fitness trade-offs between development time and parasitic potential of *A. papayae* under laboratory conditions to understand the outcome of their efficiency on different host plants.

MATERIAL AND METHODS

Maintenance of potato sprouts :

Potato was used as an alternate food source for rearing mealybugs (Serrano and Laponite, 2002). Two months old Robin eyed healthy seed potatoes were bought and kept in a dark air conditioned room for four to five days to induce sprouting. Sprouted potatoes were washed in water and disinfected with 1 per cent carbendazim solution. Later, two cm incision was given using a sharp blade and treated with gibberlic acid 100 ppm solution for half an hour. The potatoes were air dried and transferred to plastic trays (10 tubers/ tray placed at about 2 cm apart in each tray of 18'' diameter) containing solarized sand. These trays were kept in rearing room and watered gently. Eight to ten days after sowing, the potato sprouts emerged and reached a height of 4 to 6 cm and used for inoculation with mealybug.

Collection and mass culturing of *P. marginatus* on potato sprouts :

Papaya mealybugs were collected from different host plants like papaya, tapioca, cotton, mulberry, brinjal and hibiscus. They were released on potato sprouts using the camel hair brush at the rate of 3 to 5 ovisacs per potato and mealybugs on mass were obtained within 25 to 30 days of release. They were used for mass culturing of *A. papayae*. Mass culturing was also carried out in above said host plants and used for further experiments.

Mass culturing of parasitoid, *A. papayae* :

The sprouted potatoes and infested host leaves colonized with mealybugs were transferred to oviposition cages of 45×45×45 cm. Ten *A. papayae* adults were allowed inside the cage for parasitisation. After 10 days of release, the sprouts and leaves along with the mummified mealybugs were removed from the potatoes using a fine scissor and collected separately in the plastic containers. The emerged parasitoids were collected by an aspirator and observed for life history traits and parasitic potential.

Development and parasitic potential of *A. papayae* on mealybugs from different host plants :

Each assay was conducted in an experimental arena of 25 cm diameter mud pots. The mealybugs reared in different host crops and potato sprouts were used in this study. The effect of different host crops on the development time of *A. papayae* was assessed. Twenty numbers of *A. papayae* were released per plant infested with mealybugs and covered with a mylar film cage. The mealybugs reared from the potato sprouts were also taken as another source of treatment in the plastic basins. The experiment was conducted in a Completely Randomized Design (CRD) with four replications.

One week after releasing the parasitoids in the above said experiment, the sample leaves and sprouts were taken from each plant and potato sprout, respectively. They were transferred to plastic containers of 10 cm diameter covered with a muslin cloth. The containers were checked daily for parasitoid emergence and from this data, the development period and the duration of different life stages of *A. papayae* on mealybugs reared on different hosts were worked out.

Two months after releasing the parasitoids, the parasitism rate was observed in second and third instars and adult female mealybugs separately. The parasitism rate was calculated using the formula :

$$\textbf{Parasitisation rate} = \frac{\textbf{No. of parasitized maelybugs}}{\textbf{Total number of mealybugs offered}} \times \textbf{100}$$

The differences in the parasitisation rate of *A. papayae* on the mealybugs from different hosts and different stages were recorded.

Statistical analysis :

Effect of host crop influence on development time and parasitisation rate were analysed by one-way analysis of variance (ANOVA) and means were separated using LSD. The correlation and regression were applied to compute the trade-offs in the life history traits using parasitisation rate and development time.

RESULTS AND DISCUSSION

The findings of the present study as well as relevant discussion have been presented under the following heads :

Development time of *A. papayae* on mealybugs :

The development of *A. papayae* includes an egg, two larval stages and pupal stage. The total duration for the development of parasitoid, *A. papayae* (Table 1) from egg to adult in the current study was shortest in mealybugs reared from papaya (10.9 days), followed by cotton (11.8 days), mulberry (12.4 days), brinjal (13.1 days), hibiscus (14.1 days) and recorded longest days (16.3 days) of development in tapioca and 11.6 days in potato sprouts reared mealybugs. The mean duration of egg period lasted for 2.3, 2.4, 3.4, 2.5, 2.8, 2.6 and 2.3 days in mealybugs reared from papaya, cotton, tapioca, mulberry, brinjal, hibiscus and potato sprouts, respectively. The mean duration of first instar neonate nymph recorded 3.1 to 4.3 days, while the second instar mean nymph duration was 2.3 to 3.9 days and pupal period was 3.3 to 4.8 days, which were maximum in mealybugs from tapioca and minimum in mealybugs from papaya in all development stages (Table 1). The different host plants strongly affected the development time of *A. papayae* as well as that of its insect host, *P. marginatus*. The development time of *A. papayae* was partly influenced by the host crops, on which papaya mealybug feeds. Different plant species provided different nutritional quality and chemical constituents, which affected the development, reproduction and survival of an insect and it influences the behaviour and efficiency of parasitoids.

Development time, longevity, and lifetime fertility are important fitness parameters when evaluating a biological control agent. Determining development time of a parasitoid is necessary to determine its efficiency in controlling the host. Development of insecticide resistance and non-target effects of insecticides on natural enemies make chemical control a less feasible option for the long-term control of papaya mealybug (Walker *et al.*, 2003). Because of these reasons, biological control was identified as a preferred method to control the papaya mealybug.

Generally, the development time of a biological control agent should be shorter than the development time of the host (Greathead, 1986). Ulusoy and Uygun (2000) reported that host insect, *Parobemisia myricae* Kuwana finished its development in a shorter time on lemon than on trifoliate orange and developed significantly faster on vine than pomegranate, and the different host plants strongly affected the development period of the aphelinid parasitoid, *Eretmocerus debachi* Rose and Rosen as well as its host insect, *P. myricae*. Many adventive insect species become pests because they are unaccompanied by natural enemies from their native home (Orr and Suh, 1998). In the classical biological control of an adventive pest species, most often the natural enemies of the pest are searched for in its native homeland by examining the pest population in its native environment (Van Driesche and Bellows, 1996). The development period of *Eretmocerus* sp. depends on the development time of its host insect (Powell and Bellows, 1992; Sengonca *et al*., 1993), thus a short development period of *P. myricae* on a certain host plants induced a short development period of the parasitoid.

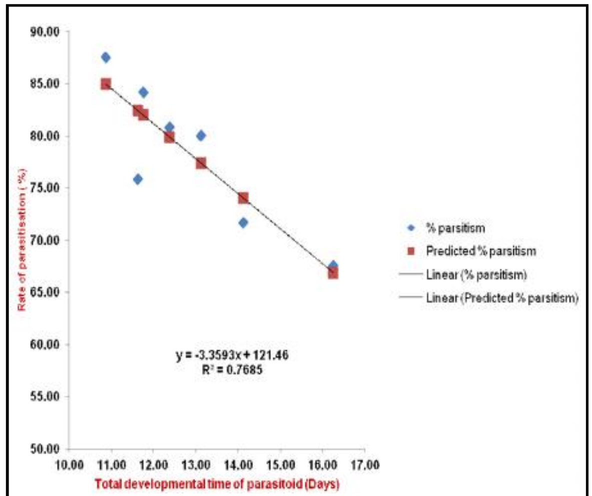

Fig. 1 : Line fit plot of regression analysis using total development time and parasitism rate of *A. papayae* on *P. marginatus* from different host plants.

Parasitisation rate of *A. papayae* on mealybugs :

When offering all seven hosts simultaneously to *A. papayae* in the experiment, papaya recorded the highest parasitisation rate with 87.5 per cent on second instar mealybugs followed by cotton (84.2%), mulberry (80.8%),

Table 1 : Development time of immature stages of *A. papayae* on *P. marginatus* from different host plants

Host	Development time (days)*				Total development time (days)
	Egg period	First instar	Second instar	Pupa	
Papaya	2.3 a ±0.29	3.1 a ±0.25	2.3 a ±0.29	3.3 a ±0.29	10.9
Cotton	2.4 ab ±0.25	3.4 ab ±0.25	2.5 ab ±0.00	3.5 a ±0.00	11.8
Tapioca	3.4 c ±0.25	4.3 d ±0.29	3.9 d ±0.25	4.8 d ±0.29	16.3
Mulberry	2.5 ab ±0.00	3.5 ab ±0.00	2.6 b ±0.25	3.8 ab ±0.29	12.4
Brinjal	2.8 b ±0.29	3.6 bc ±0.25	2.8 b ±0.29	4.0 bc ±0.00	13.1
Hibiscus	2.6 b ±0.25	4.0 bcd ±0.00	3.4 c ±0.25	4.1 c ±0.25	14.1
Potato sprouts	2.3 ab ±0.29	3.5 ab ±0.00	2.3 ab ±0.29	3.7 ab ±0.25	11.6
S.E. ±	0.22	0.18	0.22	0.20	
C.D. (P=0.05)	0.47	0.38	0.47	0.43	

*Mean and standard deviation of four replications, in a column mean(s) followed by common letters are not significantly different at 5 % in LSD brinjal (80.0%) and potato sprouts (75.8%) and recorded lowest rate of parasitisation in tapioca (67.5%) showing a significant lower acceptance for *A. papayae* (Table 2). Whereas on third instar mealybugs papaya and cotton were on par with each other by recording 54.2 and 50.8 per cent parasitisation, respectively and lowest parasitisation in tapioca (34.2 %) and in adult female the parasitisation efficiency was very low compared to other stages of mealybug. Only 22.5 per cent of parasitisation was recorded in papaya and 3.3 per cent in tapioca. In all the crops, parasitoids recorded higher parasitisation rate on second instar mealybugs than third instar and adult female. It might be due to less defensive behaviours (eg., kicking) performed by second instar nymphs (Zepeda Paulo *et al.*, 2013) and it was already reported as a high-quality resource for *A. papayae* being normally preferred over other nymphal stages.

From the Table 2, it is also inferred that the parasitoid had the highest efficiency on second instar mealybug and so it was taken to be correlated with total development time of parasitoid. The parasitisation rate decreased as development time increased and *vice versa.*

The correlation and linear regression analysis comparing the total development time with parasitisation rate resulted in the negative correlation co-efficient ($r2$ = -0.88) and the equation y = -3.3593x + 121.46 (R^2 = 0.7685 and P= 0.009) (Fig. 1). Therefore, the percentage of parasitisation was significantly affected by the total development time of parasitoid inturn influenced by the host plants. The lowest level of parasitisation (67.5 %) occurred at 16.3 days of development in tapioca reared mealybugs and the highest (87.5%) at 10.9 days of development in papaya reared mealybugs (Table 3). It is concluded that the development time of parasitoid was inversely correlated with the parasitic potential and they were significantly different with each other. These differences could be attributed to differences in plant host of mealybugs (Campbell *et al.*, 1974 and Wagner *et al.*, 1984).

Calatayud *et al.* (2001) while studying the interactions between cassava mealybugs and its major parasitoids, *Apoanagyrus diversicornis* Howard, *Aenasius vexans* Kerrich and *Acerophagus cocois* Smith reported that negative effect on parasitoid development in cassava crop was due to biochemical changes in the leaves induced by water deficiency. Plant factors that alter the herbivores growth, fecundity and survival were most likely to negatively affect the third tropic level (Painter, 1951). Cynogenic glycosides present in tapioca plants may disfavour most of the beneficial natural enemies (Van

Table 2 : Parasitic potential of *A. papayae* on *P. marginatus* from different host plants

Host	Mean parasitisation rate (%) *		
	2nd instar	3rd instar	Adult
Papaya	87.5a	54.2a	22.5a
Cotton	84.2ab	50.8ab	20.0ab
Tapioca	67.5f	34.2c	3.3e
Mulberry	80.8bc	47.5abc	15.8b
Brinjal	80.0cd	44.2ac	10.8c
Hibiscus	71.7ef	37.5c	5.0d
Potato sprouts	75.8de	37.5c	5.8de
S.E. ±	1.37	1.01	1.60
C.D. = (P=0.05)	2.88	2.10	3.33

*Mean and standard deviation of four replications, in a column mean(s) followed by common letters are not significantly different at 5 % in LSD

Table 3 : Total development time and parasitisation rate of *A. papayae* on *P. marginatus* from different host plants

Plant host	Total development time (Days)	Mean parasitisation rate on second instar mealybug (%)
Papaya	10.9	87.5
Cotton	11.8	84.2
Tapioca	16.3	67.5
Mulberry	12.4	80.8
Brinjal	13.1	80.0
Hibiscus	14.1	71.7
Potato sprouts	11.6	75.8
Correlation	Correlation co-efficient r2= -0.88	
Regression	Regression equation y = -3.3593 x + 121.46	R^2 = 0.7685 and P= 0.009

Emden and Hagen, 1976). A more complex evolutionary response to plant chemical defense was found in herbivores that have co-opted these toxins for their own benefit by sequestering them and using them as a defense against natural enemies reported by Bowers (1990), Nishida (2002) and Hartmann (2004). A diet with high concentrations of secondary metabolites has greater parasitisation rates than that feeding on diets with low concentrations of secondary metabolites as reported by Dyer *et al.* (2004).

Finally from this study, it is concluded that when there will be earlier the development of parasitoid, higher will be the parasitisation efficiency and *vice versa*. It might be due to the effective compartmentalization of energy by parasitoid that it conserves more energy, when developed early and uses the same energy for parasitisation process. In papaya reared mealybugs, the parasitoid developed more quickly than other crops and had more parasitisation. In tapioca, it developed slowly than other crops and had less parasitisation. The preference level of parasitoid, *A. papayae* was maximum to papaya and minimum to tapioca. And so it was concluded that there was a fitness trade-offs between the development time and parasitisation rate of the parasitoid. Increased development time and decreased parasitisation rate could suggest that it might be due to the biochemicals and volatiles present in the host plants that triggered changes in the preference of papaya mealybug and it indirectly induced the efficiency of parasitoid. The parasitoid mostly preferred the second instar of mealybugs compared to third instar and adult female.

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