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Research Article

Effect of native and non-native hosts on the biology of *Acerophagus papayae* Noyes and Schauff, the introduced parasitoid of *Paracoccus marginatus* Williams and Granara De Willink

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ABSTRACT: The bioecology study of any parasitoid using alternative hosts imposes divergent selection pressures on parasitoid populations. In this study, we investigated the bioecology potential of parasitoid *Acerophagus papayae* Noyes and Schauff on papaya mealybug *Paracoccus marginatus* Williams and Granara De Willink from different plant hosts. The parameters studied were adult longevity (survival of progeny), fecundity and productivity of female mealybugs and sex ratio of progenies of *P. marginatus*. The results showed significant differences in bioecology of parasitoid on their natal host (*P. marginatus* from papaya) compared with the non-natal hosts (*P. marginatus* from non papaya hosts). It is also compared with honey concentration solution and potato sprouts. The parasitoid is well adapted to the natal host that is papaya compared to others host. However, parasitoids showed a similar high fitness on both natal and non natal hosts. This results could be used to increase the effectiveness of biological control programme on different views.

KEY WORDS: *Acerophagus papayae*, *Paracoccus marginatus*, native hosts, non native hosts, biology

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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 and causes severe yield losses. *Acerophagous papayae* Noyes and Schauff is effective in controlling papaya mealybug, when inoculatively released at the rate of 100/ village. Generally, in order to reproduce, a female parasitoid must find its host at a stage suitable for parasitization. The host selection process involves a sequence of phases mediated by physical and chemical stimuli from the host, the substrate, and/or associated organisms, eventually leading to successful parasitism (Vinson, 1985; Godfray, 1994). Because parasitoid foraging time is limited and the potential cues available are numerous, the parasitoid faces the need to optimize exploitation of available cues and discriminate those most reliable in indicating the presence of a suitable host (Hilker and Meiners, 2006). In response to selective pressures, these populations may follow different evolutionary trajectories. Divergent natural selection could promote local host adaptation in populations, translating into direct benefits for biological control *vis-a-vis* bioecology potential of the parasitoid. Here, the study has taken the adaptive plasticity hypothesis as a starting point for evaluating bioecology of parasitod on host from different local environment (plant hosts).

Hence the present study deals with the biology of introduced populations of *A. papayae* to *P. marginatus* from different host plants. In connection with this, to investigate the local host adaptation via bioecology, the hypothesis that each parasitoid population had a higher fitness on its own host (natal host) than on other non-natal mealybug hosts was tested. To find this, the study was conducted using longevity experiments and to determine the different traits of bioecology of host associated parasitoid populations across different mealybug hosts.

MATERIALS AND METHODS

Collection and mass culturing of *Paracoccus marginatus* on potato sprouts

Potato could be used as an alternate food source for rearing of mealybugs (Serrano and Laponite, 2002). Two months old Robin eyed healthy seed potatoes were bought from local markets and kept in a dark air conditioned room for four to five days to induce sprouting. Sprouted potatoes were washed in water and disinfected using 1 % carbendazim solution. Later, two cm incision was made 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 (each plastic tray @ 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 grew and reached a height of 4 to 6 cm and used for inoculation with *P. marginatus*.

Paracoccus marginatus was collected from different host plants like papaya, tapioca, cotton, mulberry, brinjal and hibiscus. They were released into potato sprouts using the camel hair brush. Sufficient number of *P. marginatus* were obtained within 25 to 30 days of release which in turn were used for mass culturing of *A. papayae*. Mass culturing was also carried out in above host plants and used for further experiment. The sprouted potatoes and infested host leaves colonized with mealybugs were transferred to oviposition cages of 45 x 45 x 45 cm. Ten numbers of *A. papayae* were allowed inside the cage for parasitization. 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 using an aspirator and used for further experiments.

Biology and productivity of *Acerophagus papayae* on *Paracoccus marginatus* from different host plants

Adult longevity of *Acerophagus papayae*

To determine the adult longevity of the *A. papayae*, nine sets of recipe having leaves of six host plants (papaya, tapioca, cotton, hibiscus, mulberry and brinjal) potato sprouts, two sets with different concentration of honey solution (10, 50 per cent) and water alone as control were used. For each set of recipe, 10 insects were used and replicated for 10 times. Freshly emerged adults from different sources were sexed and confined singly in glass test tubes having some quantity of food source and covered with white cloth. This set up was kept in room temperature and left undisturbed. Confined adults were monitored daily for survival and observations were made till the last insect of the cohort.

Lifetime fertility of *Acerophagus papayae*

A virgin female was allowed to mate with five newly emerged males for 24 hours in a glass tube provided with honey and water. After mating, the males were removed and the females were individually transferred to plastic jars. Before placing the lid, each jar was covered with a piece of khada cloth. A hole was made in the lid to allow air circulation. Approximately 300 second-instar female mealybugs collected from different host plants *viz.* papaya, tapioca, cotton, hibiscus, mulberry, brinjal and potato sprouts were provided daily to parasitoids for oviposition until they die. The leaves and sprouts with parasitized mealybugs were placed in plastic container for mummification. After the emergence of parasitoids, offsprings per female parasitoid, total number of parasitoids emerged and the number of males and females were counted. The fecundity of the parasitoids was recorded by counting the number of parasitoids emerged from each vial and calculated for a single female. The total number of the parasitoids emerged were recorded by counting the number of parasitoids emerged per diet. From the emerged *A. papayae*, male and female progenies were separated. The males were smaller in size compared to the female progenies. Females were distinguished by the presence of ovipositor.

RESULTS AND DISCUSSION

Survival of the progeny (Adult longevity)

The survival of the progeny was studied by taking the mean proportion of longevity of parasitoids emerged from the mummified *P. marginatus* (Table 1). A significant effect was found on the mean survival of the parasitoid progeny for the parasitoid population. On natural host papaya the parasitoid longevity was high (12.33 days) which significantly differed from non natal hosts. Cotton (10.67 days), mulberry (10.33 days), potato sprouts (9.67 days) which were on par with each other while tapioca and hibiscus recorded very low survival of 8.67 days.

The provision of adult food greatly influenced the longevity of *A. papayae*, according to Sakthivel (2011), who reported that there was no significant difference in adult longevity of *A. papayae* (7.2 and 7.0 days) when 100 and 50 per cent honey were provided as adult food whereas, the adults survived for a period of 3.8 days without food. And the result was in close agreement with the findings of Attaran *et al.* (2004), who opined that the adult females of *Trichogramma brassicae* Bezdenko provided with honey lived 8.06 days in comparison with 2.04 days for the unfed females. Another study by Kim and Morimoto (1995) proved that many parasitoids required carbohydrate rich non-host foods for survival and in the absence of hosts, parasitoids which were given carbohydrate rich food *viz*., dilute honey solution, lived significantly longer than those given only water. Life span extension of many parasitoids was mainly determined by carbohydrates (Giron *et al.,* 2002). This might be the reason for difference observed in the longevity of *A. papayae* among the host plants having varying level of carbohydrate in their leaves. Similar results were obtained by Hemerik (2007), who studied the adult longevity of *Diadegma semiclausum* Hellen, parasitoid of *Plutella xylostella* (L.) on different nerctar sources. Sagarra *et al.* (2000) concluded that adult parasitoid *Anagyrus kamali* Moursi of hibiscus mealybug *Maconellicoccus hirsutus* (Green) provided with food lived approximately 20 times longer than unfed individuals. The present findings of adult longevity were in line with Divya *et al.* (2011), who reported that honey 10%, honey 50%, yeast extract+ honey 10%, dried grape extract and fructose significantly increased adult longevity and parasitization rate of *A. papayae, Anagyrus loecki* Noyes and Menezes and *Pseudoleptomatrix mexicana* Noyes and Schauff on *P. marginatus*. The present study demonstrated the importance of energy requirement for adult longevity of *A. papayae*. According to Greathead (1986), high fecundity and short generation time are some of the desirable characters of a parasitoid.

Lifetime fertility

Off springs per female

The offspring production was the highest (55.9 ± 1.2) in papaya followed by cotton (50.8 ± 1.0), potato (50.8 ± 1.0) and mulberry (45.4 ± 0.7). The offspring production in the control was the least (20.5 ± 0.85). The least among the treatment was honey 20% where mean offspring production was 27.8 ± 1.5, whereas 10 per cent honey recorded 43.4 ± 1.8 offsprings which is higher than reproduction in hibiscus and tapioca (Table 1). There was a statistically significant difference observed by one-way ANOVA (F-988.6, p<0.0001) in female parasitoid production among host plants and the control.

This was supported by Thompson (1990), who reported that the *A. papayae* not fed with honey or sugar solutions or not supplemented by other nutrients generally displayed reduced longevity and/or fecundity. In the current study in which the effect of different adult diets on fecundity and longevity were compared and offspring production was high in host plants than that of honey solutions. This might be due to the sugars that occur naturally in nectar or honeydew increased longevity of *A. papayae*, and that host-feeding provided materials for egg maturation in many host-feeding species (Heimpel and Collier, 1996). Sugar sources significantly increased adult longevity, parasitization rate and number of offspring per female of *A. papayae*. The present investigation supported the findings of Divya (2012), who inferred that the number of offsprings per female of *A. papayae*, *A. loecki* and *P. mexicana* were found to be high in nutrition fed adult parasitoids compared to the control fed with only with water. The results were more or less in the line with the findings of Olson and Andow (1998) and Heimpel and Collier (1996).

Total number of progeny parasitoids emerged

The parasitoid emergence was the highest (279.5 ± 6.0) in papaya followed by cotton (254.0 ± 5.2) and potato (254.0 ± 5.2). Mulberry and brinjal recorded 227.0 ± 3.5 and 226.0 ± 2.1 parasitoids respectively, and they were followed by honey 10 % (217.0 ± 9.2), whereas honey (20%) recorded an emergence of 140 ± 8.2. The mean emergence in the control was only 105.5 ± 4.2 and was the least when compared with the nutritional source of plants and diets. There were statistically significant differences by one-way ANOVA (F-945.2, p<0.0001) in parasitoid emergence among host plants and the control. When each host plant was compared with control (Dunnett's test), there was statistically significant higher emergence in all of the host plants (Table 1). The emergence farthest from that of the control was in papaya and the closest being honey 20% source.

The present investigation was in close agreement with the findings of Amarasek are *et al.* (2012), who reported that production and emergence of *A. papayae* offsprings varied significantly with mealybug from different host crops. Uckan and Ergin (2002) found that the host diet affected the developmental time, fecundity, sex ratio, and size of *Apanteles galleriae* Wilkinson, a parasitoid of *Achroia grisella* (F.) Similar results were obtained by Divya (2012), who reported that honey 10%, honey 50%, yeast extract+honey 10 %, dried grape extract and fructose significantly increased total number of progeny produced in all three parasitoids of *P. marginatus i.e. A. papayae*, *A. loecki* and *P. mexicana*. In the present study, the emergence rate of adults *A. papayae* vary with the size and type of the host egg, number of *A. papayae* that develop per egg, development period in host eggs and temperature (Doyon and Boivin, 2005). The emergence of Trichogrammatid parasitoids was higher on host eggs reared on sorghum (91.09%) than on maize (82.91%) Krishnamoorthy (2012). Puneeth and Vijayan (2013), reported the significant difference of the emergence and survival of *T. chilonis* on eggs of *Corcyra cephalonica* (Stainton) reared on grains of millet, wheat, rice and sorghum. This might be due to eggs from different host plants may favour *A. papayae* development because of the greater use of the food reserves with a single *A. papayae* developing per egg, due to lack of competition. Hoffmann and McEvoy (1985), supported this by the report that the number of adults develop per egg varies with the availability of host eggs for the parasitoid that increases as the egg availability decreases.

Female sex ratio

A statistically significant difference was observed by one-way ANOVA (F-226.8, p<0.0001) in sex ratio among host plants and the control. When each host plant was compared with control (Dunnett's test), there was statistically significant higher emergence of females in all of the host plants (Table 1) except honey 10% and honey 20%. The female skewed sex ratio farthest from that of the control was in papaya and the closest being honey 10%. The sex ratio skewed towards females was highest in papaya (80.9 ± 2.4 %) followed by cotton (70.5 ± 2.4 %), mulberry (62.2 ± 3.2 %) and potato (60.6 ± 1.5 %). The least among the host nutrition was honey (20%) where mean female ratio was 36.2 ± 5.0, which was lower than the control (40.2 ± 5.5 %). Similar results were obtained by Divya (2012), that the diets honey 10%, honey 50%, yeast extract+honey 10 %, dried grape extract and fructose significantly increased the female progeny production in three parasitoids *viz., A. papayae, A. loecki* and *P. mexicana.* The present findings concluded that the sex ratio varies with the host plants. It was supported by Chaturwedi *et al.* (2013), who reported the sex ratio of *T. chilonis* was varied with different host plants. However, results are in contrast with Karimian and Sahragard (2000), who reported that females of *T. brassicae* provided with honey produced decreased proportion of female progeny (66.67) when compared to unfed females (83.82 %). The females of *Trichogramma* species with longer longevity was known to produce more males probably due to sperm depletion as reported by Kuhlmann and Mills (1999). Studies carried out by Malati and Hatami (2010) also reported that 50 per cent of progeny were females for honey fed group, whereas it was 75 per cent for the unfed group of *T. brasiliensis* parasitoids.

In another study, Leatemia *et al.* (1995) reported that honey fed, mated parasitoid *Trichogramma minutum* Riley held without access to host for up to 16 days at 25^{0}C or 28 days at 16^{0}C were able to produce female offsprings when allowed to parasitize. The results are also conform with the findings of Godfray (1994) that when hosts vary in quality, females gain more fitness than males, and fertilized females may produce more female progenies to larger (or high quality) hosts and more male progenies to smaller (low quality) hosts. Progeny sex ratio of *Campoletis sonorensis* (Cameron) could also be affected by the female parasitoid density, presence of males and by the host plant and/or diet quality (Tong *et al.,* 2012). This might be the reason for female biased sex ratio in the present study. It was in contrast with male biased sex ratios reported by Hoelscher and Vinson (1971) but agrees with Noble and Graham (1966). Hoelscher and Vinson (1971) and Lingren *et al.* (1970) reported that the proportion of males is usually greater than that of females in field-collected and laboratory-reared *C. sonorensis.* Some of the earlier findings were in agreement with the present study, the decrease of female sex ratio or increase of male sex ratio with host plants might be due to the increase of parasitoid density and the rate of superparasitism (Hofsvang and Hågvar, 1986). In that situation the female lays more male eggs (Werren, 1980) and the parasitised hosts provide less sources for larval development of parasitoid than the healthy hosts (Honek *et al.,* 1998) and it produced more number of males because of their lower nutritional quality (Charnov, 1982), and change their sex ratio (Waage, 1986).

Table 1. Parasitoid virulence of adult longevity, productivity of female and male-female sex ratio of *Acerophagus papayae* on *Paracoccus marginatus* from different local host environment

P. marginatus source host	Biological parameters of parasitoid			
	Adult longevity (days)	Total number of *A. papayae* emerged (numbers)	Offsprings/ female (numbers)	Proportion of females (per cent)
Papaya	12.3^a	279.5^a	55.9^a	80.9^a
Cotton	10.5^b	254.0^b	50.8^b	70.5^b
Tapioca	8.4^d	179.0^f	35.8^f	50.0^d
Mulberry	10.3^b	227.0^c	45.4^c	62.2^c
Brinjal	9.4^c	226.0^c	45.2^c	50.9^d
Honey 10%	8.8^d	217.0^d	43.4^d	43.8^e
Honey 20%	8.7^d	207.0^e	41.4^e	60.6^c
Hibiscus	8.6^d	254.0^b	50.8^b	40.7^f
Potato	9.7^c	140.0^g	27.8^g	36.2^g
Control	4.6^e	105.5^h	20.5^h	40.2^f
ANOVA value	F – 159.8 *P*<0.0001	F – 945.2 *P*<0.0001	F – 988.6 *P*<0.0001	F – 226.8 *P*<0.0001

*Values are mean of three replications

For evaluating a biological control agent, developmental time, longevity, and lifetime fertility are the important fitness parameters. Determining developmental time of a parasitoid is necessary to determine its efficiency in controlling the host. In general, the developmental time of a biological control agent should be shorter than the developmental time of the host (Greathead, 1986). According to Greathead (1986), high fecundity and short generation time are some of the desirable characters of a parasitoid. Courtship and mating are energy and time consuming activities in insects, which will affect the longevity, lifetime fecundity, and progeny production of parasitoids (Uckan and Ergin, 2002). Mating is required to achieve their full reproductive potential in some parasitoids. The sex ratio of parasitoids can be affected by mating as they need to mate once to attain their optimal sex ratio. Some parasitoid species are arrhenotokous, e.g. fertilized eggs lead to female progeny and unfertilized eggs give rise to males. Lifetime fertility of a parasitoid is important in establishment as a effective biological control agent. A parasitoid with higher lifetime fertility with female-biased progeny can parasitize a higher number of hosts. Female-biased progeny are desirable in classical biological control (Obrycki and King, 1998).

Our present study revealed that the parasitoid *A. papayae* is well adapted to *P. marginatus* from natal host papaya than the non-natal hosts which reaffirms the usefulness of this experiment to study adaptation in biological control agents to target hosts. The future studies can be focused on the adaptive mechanism of parasitoids living in changing environments (different food source), shaping the effect of plasticity of parasitoids on the efficiency of pest control, and enumerating the relative frequency and dynamics of these *A. papayae* and PMB-host populations in the field usage.

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