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Influence of the Host Plant on the Encyrtid *Aenasius bambawalei*, a Parasitoid used to Control the Cotton Mealybug, *Phenacoccus solenopsis*, in Pakistan

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HH and FU planned and designed the experiments. HB, HU and BA executed and performed the experiments. PAC, HB and FU analyzed the data. HU and BA contributed in host plants collection/materials. HB, PAC and HU wrote the manuscript.

Key words
***Phenacoccus solenopsis*, *Aenasius bambawalei*, % parasitism, parasitoid fitness, host plants**

ABSTRACT

The mealybug *Phenacoccus solenopsis* Tinsley (Sternorrhyncha: Pseudococcidae) is a highly polyphagous pest of fruits, vegetables, crops and ornamentals in Pakistan. Biological control approach by using *Aenasius bambawalei* Hayat (Hymenoptera: Encyrtidae) has been developed recently to control this pest. However, the efficiency of this parasitoid is variable according to the locality and the plants on which *P. solenopsis* is feeding. In this context, this experiment investigated under field and laboratory conditions the influence of the host plant of *P. solenopsis* on the parasitism success and the female fitness of *A. bambawalei*, Five plant species, commonly found to be host of *P. solenopsis,* were tested: hibiscus, potato, okra, eggplant and tomato. Under no choice test conditions, the results showed that the % parasitism did not differ significantly between different host plants in laboratory and field conditions. In contrast under multiple choice test conditions, the % parasitism (65.00±3.75, 60.00±2.83, 51.88±1.88, 69.38±2.54, 60.63±2.80 under field conditions and 63.13±2.71, 61.25±2.60, 49.38±2.54, 68.13±2.37, 53.75±2.5 under lab condition for okra, tomato, brinal, hibiscus and potato respectively) significantly differed between plants showing higher parasitism on hibiscus as compared to the other plant species tested. Moreover, the % parasitism generally decreased drastically when the time of exposure on mealybug hosts increased. In addition, the host plants species influenced significantly the female fitness of the parasitoid expressed in term of hind tibia length and body weight. The female parasitoids coming from mealybugs fed on hibiscus exhibited a significantly longer tibia and body weight than the parasitoids coming from the mealybugs reared on the other plants. The host plants did not influence the sex ratio of the 3rd trophic level. The current study indicated that hibiscus is, among those tested in this study, the best plant species to mass rear the mealybug and its associated parasitoid in a context of biological control program. However, additional research is needed to assess the properties of hibiscus to attract the parasitoid.

INTRODUCTION

The mealybug *Phenacoccus solenopsis* (Sternorrhyncha: Pseudococcidae) is a highly polyphagous pest (Rashid *et al*., 2012), feeding on more than 154 plant species including fruits, vegetables, crops and ornamentals in Pakistan (Arif *et al*., 2009). Biological control approach by using *Aenasius bambawalei* (Hymenoptera: Encyrtidae) has been developed recently to control this pest (Arif *et al*., 2012; Fand *et al*., 2011; Venilla *et al*., 2010; Nagrare *et al*., 2009). However, the parasitism efficiency of this parasitoid is variable (Iqbal et al., 2016) according to the locality and the plants on which *P. solenopsis* is feeding (Arif *et al*., 2012; Persad *et al*., 2012). There is therefore a need to investigate the influence of the host plant of *P. solenopsis* on the efficiency of *A. bambawalei.*

Hymenopteran parasitoids lay their eggs in the body/abdomen of their hosts and the parasitoid larvae are entirely dependent on the host for their development, as they feed internally in the host to complete their whole development (Godfray, 1995). Their fate is therefore strongly linked with the fate of the host, at an individual as well as at population level (Tanja *et al*., 2003).

Plants not only influence the herbivorous insect developments but also those of their associated natural enemies (Arif *et al*., 2012). Host plant affect parasitoid fitness by a variety of means, including survivorship, clutch size, body size, and/or fecundity and negative impacts on

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parasitoid fitness may occur when the developing parasitoid encounters the plant toxin in the hemolymph or tissue of its herbivorous host (Ode, 2006). Both physical and chemical characteristics of plants are known to influence significantly the efficacy of biological control agents by influencing their abundance, survival, development time, fecundity, and rate of attack (Consuelo *et al*., 2000). Host plants structure and morphology can strongly affect the location and acceptance ability of the parasitoids to exploit their hosts (Wang *et al*., 2009, 2013). Yang and Sadof (1995) reported that *Coleus sp* leaf variegation affects the rate of fecundity, survivorship, and population growth of both the citrus mealybug, *Planococcus citri* (Risso), and its parasitoid, *Leptomastix dactylopii* (Howard). Host plant quality or size is commonly correlated to parasitoid fitness, especially in idiobiont parasitoids, whose offspring may depend on the quality and size of the host at the time of oviposition (Gols and Harvey, 2008; Fortuna *et al*., 2012).

It has been well documented that the parasitism level of *A. bambawalei* varies with respect to the host plants (Arif *et al*., 2012; Fand *et al*., 2011; Venilla *et al*., 2010, Nagrare *et al*., 2009). However, the direct influence of the host plant on this parasitoid species was never demonstrated. In this context, we investigated the direct influence of the host plant, frequently found infested in the field by *P. solenopsis,* on the parasitism (behavioural aspects, success of parasitism and fitness) of *A. bambawalei* under field and laboratory conditions through choice and no choice bioassays.

MATERIAL AND METHODS

Plants

Five plant species (hibiscus, potato, okra, eggplant and tomato) were used in this study because *P. solenopsis* is frequently found to feed on them in the field (Arif *et al*., 2009). For field experiments, plants of hibiscus of a minimum of 3 years old grown in the Institute as ornamental plants were directly used. Plants of eggplant and tomato were grown first at a nursery in the field during 4-6 weeks before to be transplanted individually in small pots while plants of potato and okra were directly raised in the small pots during 4-6 weeks for experiments. For laboratory experiments, the shoots (12-15 cm) with tender leaves were collected from each of the four plants and fixed in glass conical flasks or bottles of 75 ml and 200 ml respectively. All plants were grown in the fields of the Agricultural Research Institute (ARI), Tarnab Peshawar-Pakistan.

Host rearing

In order to get colonies of *P. solenopsis* from each of the five host plants, *P. solenopsis* was reared on the five aforementioned respective host plant species during four generations. For both field and laboratory experiments, gravid females of *P. solenopsis* from each of the five host plants, which were near to form nymphs sacs, were selected and individually put on 10-12 cm shoot with tender leaves on each of their respective host plant species and then covered with a very fine nylon cloth of mesh size 0.002 mm. After few days, the female started to produce young nymphs which were then transferred to their respective host plant species. Thereafter, when the nymphs reached to the adult stage they were transferred to new fresh shoots of their respective host plant species and left for giving young nymphs that will grow up to adults. For each host plant, this process was repeated to obtain 4 generations of 5 different *P. solenopsis* colonies. For field experiments, all colonies of *P. solenopsis* were reared directly on plants grown in the field while the colonies used for laboratory experiments were reared on leaves of their respective host plants in Petri dishes/plastic jars.

Parasitoids

The parasitoids were separately reared on each *P. solenopsis* colonies living separately on five host plant species. On each host plant, *P. solenopsis* adults which were near to form nymphs sacs were selected and covered by a very fine nylon cloth of mesh size 0.002 mm. After two days, *P. solenopsis* produced more than 50 nymphs at the same age. When the nymphs were fully spread on the shoots, the adults were removed. On each host plant, when most of the mealybug's nymphs reached the 3rd instar then a pair of *A. bambawalei* was released inside the nylon bag for parasitization. After 24 hr, the parasitoid pair was removed and the nymphs were kept for mummy formation. This process was repeated to obtain 4 generations of 5 different *A. bambawalei* colonies on each *P. solenopsis* colony living separately on five host plant species.

Parasitism under field conditions

No choice bioassays

In order to determine the percent of *A. bambawalei* parasitism under field conditions in no host-plant choice conditions, the upper shoots (12-15 cm) with tender leaves of each of the host plant were infested by 20 mealybugs of 2nd instar, 3rd instar, pre-ovipositing and adult females (a total of 80 mealybugs/host plant) and covered with nylon bag to avoid any nymphs/mealybug escape and to protect them from ants. These mealybugs were allowed to forage for 24 hrs to become fully established. Thereafter, one pair of freshly emerged *A. bambawalei* from the respective host plant was introduced and covered with nylon bag to protect them from other natural enemies' parasitism and predation.

The parasitoids were allowed to forage for parasitism for one week. Thereafter, the parasitoid pair was removed and transferred to another shoot which was previously infested by 20 mealybugs of each instar on the same pattern of 1st week. After 2nd week, the parasitoid pair was removed and placed in another new shoot during 3rd week (if still alive) which was previously infested by the same pattern as during 1st and 2nd week. Weekly observations were made on pupae (mummies) formation and parasitoid emergence (*P. solenopsis* mummy that did not show emergence hole of an adult parasitoid during this time were noted as dead). Data on % parasitism, % emergence and sex ratio, female hind tibial length (mm) evaluated on 10 individuals and body weight (mg) evaluated on 5 individuals were recorded. This experiment was replicated ten times (n=10).

Host-plant choice test

In order to determine the percent of *A. bambawalei* parasitism under field condition in multiple host-plant choice conditions, for each host plant in small pots the upper shoots (12-15 cm) with tender leaves were infested randomly by 4 mealybugs each of 2nd instar, 3rd instar, pre-ovipositing and adult females together (16 mealybugs/plant i.e. a total of 80 mealybugs on all five host plants). Then all these pots were covered under a single nylon cloth to avoid any nymphs/mealybugs from escape and to protect them from ants. These mealybugs were allowed to forage for 24 hrs to become fully established. Thereafter, one pair of freshly emerged *A. bambawalei* was introduced. The parasitoids were allowed to forage for parasitism of mealybugs freely on all five host plants for one week. Thereafter, the parasitoid pair was removed and the shoots were covered separately by nylon bag and the same parasitoid pair was then transferred to other shoots, which were previously infested randomly by 80 mealybugs (16 individuals/host plant) of 2nd instar, 3rd instar, pre-ovipositing and adult female. After one week, the pair of parasitoid was removed and if still alive then placed on other new shoots (for 3rd week of parasitism) previously infested randomly by 80 mealybugs on the same pattern as during 1st and 2nd weeks. Weekly observations were made on pupae (mummies) formation and parasitoid emergence. Data on % parasitism, % emergence and sex ratio, female hind tibial length (mm) evaluated on 10 individuals and body weight (mg) evaluated on 5 individuals were recorded. This experiment was replicated ten times (n=10).

Parasitism under laboratory conditions

No host-plant choice test

For each of host plants, the shoots fixed in glass conical flasks were infested by 20 mealybugs of 2nd instar, 3rd instar, pre-ovipositing and adult females (i.e. total of 80 mealybugs/host plant). When these mealybugs become fully established on each host plant then a pair of freshly/young emerged *A. bambawalei* from the respective colony according to the host plant used was introduced and allowed to forage and parasitize the mealybugs for one week. After one week the parasitoid pair was removed and each shoot was covered again inside the nylon cloth. The same parasitoid pair was transferred to other conical flask (plant shoot) for another week of parasitism where each shoot was previously infested by 20 mealybugs of 2nd instar, 3rd instar, pre-ovipositing and adult female on the same pattern of 1st week. The parasitoid pair was allowed to stay there for one week and then shifted (if still alive) to another conical flask with new shoot infested with 20 mealybugs of 2nd instar, 3rd instar, pre-ovipositing and adult female (i.e. total of 80 mealybugs/host plant) for 3rd week of parasitism. After removing the parasitoid, the pupae (mealybugs mummies formed) were covered inside the nylon cloth till the adult emergence occurred. Data on % parasitism, % emergence and sex ratio, female hind tibial length (m) evaluated on 10 individuals and body weight (mg) evaluated on 5 individuals were recorded. This experiment was replicated ten times (n=10).

Host-plant choice test

For each of host plants, the shoots fixed in glass conical flasks were randomly infested by 16 mealybugs/host plant) of 2nd instar, 3rd instar, pre-ovipositing and adult female together (i.e. a total of 80 mealybugs on all five host plants). Then a pair of freshly/young emerged *A. bambawalei* was introduced and allowed to forage and parasitize the mealybugs freely on all five host plants previously infested for one week. After one week the parasitoid pair was removed and each shoot was covered separately again inside the nylon cloth. The same parasitoid pair was transferred to other conical flask (plant shoot) for 2nd week of parasitism where these shoots were previously infested randomly by 16 mealybugs/host plant (a total of 80 mealybugs on all host plants) of the same mealybug instars. The parasitoid pair was allowed to stay there for one week and then shifted (if still alive) to another conical flask with new shoots previously infested by 16 mealybugs/host plant on the same pattern of 1st and 2nd week (a total of 80 mealybugs on all host plants) of the same instars as offered during 1st and 2nd week. After removing the parasitoid, the pupae (mealybug mummies formed) were covered inside the nylon cloth till the parasitoid emergence occurred. Data on % parasitism, % emergence and sex ratio, female hind tibial length (mm) evaluated on 10 individuals and body weight (mg) evaluated on 5 individuals were recorded. This experiment was replicated ten times (n=10).

Statistical analyses

All the data where needed were first transformed statistically and then subjected to ANOVA through a Completely Randomized Design (CRD). Untransformed results are presented in the tables. Means were separated by LSD at 5% level. Statistical tests were done using STATISTIX 8.1 package.

RESULTS

Parasitism under field conditions

No choice bioassays

The results showed that the host plants influenced significantly the parasitism only at the third week of parasitism (Table I; $F_{4, 45}$=0.32; p=0.8646 at the 1st week; $F_{4, 45}$=0.21; p=0.9313 at the 2nd week and $F_{4, 45}$=10.4; p=00001 at the 3rd week). In fact, a negative correlation was observed between parasitism and the time passed for parasitism (r = -0.9693). However, the parasitism was significantly lower at the 3rd week as compared to the previous weeks regardless of the host plant used. No difference was obtained for the % parasitoid emergence as well as for the sex ratio over the 3 weeks of parasitism ($F_{4, 45}$=0.54; p=0.7078 for the 1st week; $F_{4, 45}$=0.51; p=0.7267 for the 2nd week and $F_{4, 45}$=0.06; p=0.994 for the 3rd week; for sex ratio; $F_{4, 45}$=0.07; p=0.9898). In contrast, the host plants influenced significantly the fitness of the parasitoid in terms of female hind tibial length and body weight. The female parasitoids coming from mealybugs reared on hibiscus exhibited a significantly longer hind tibia ($F_{4, 45}$=6.31; p=0.0004) and body weight ($F_{4, 45}$=3.95; p=0.0079) than the parasitoids coming from the mealybugs reared on the other plant species (Fig. 1).

Table I.- Influence of *Phenacoccus solenopsis* host plants on the parasitism of *Aenasius bambawalei* under field conditions (no choice bioassays) during three consecutive weeks of parasitism (means[1] ± SE, n=10).

Host plants	Percent parasitism (weeks)			Percent parasitoid emergence (weeks)		
	1st	2nd	3rd	1st	2nd	3rd
Okra	56.63 ± 2.33a	23.63 ± 1.05a	4.25 ± 0.21a	86.69 ± 0.70a	88.31 ± 0.53a	91.67 ± 05.69a
Tomato	56.38 ± 1.62a	23.63 ± 1.46a	2.88 ± 0.19b	87.99 ± 01.13a	88.55 ± 01.37a	91.67 ± 05.69a
Eggplant	54.50 ± 1.88a	23.00 ± 1.45a	2.75 ± 0.31b	86.63 ± 0.66a	87.67 ± 0.90a	91.67 ± 05.69a
Hibiscus	57.00 ± 2.31a	24.50 ± 1.53a	4.38 ± 0.21a	87.06 ± 0.92a	89.06 ± 01.05a	90.00 ± 05.09a
Potato	54.75 ± 1.93a	23.00 ± 2.02a	3.00 ± 0.20b	86.57 ± 0.45a	87.39 ± 0.58a	88.33 ± 06.11a

[1]Means in each column followed by the same letters are non significant at 5% level, using LSD test following ANOVA.

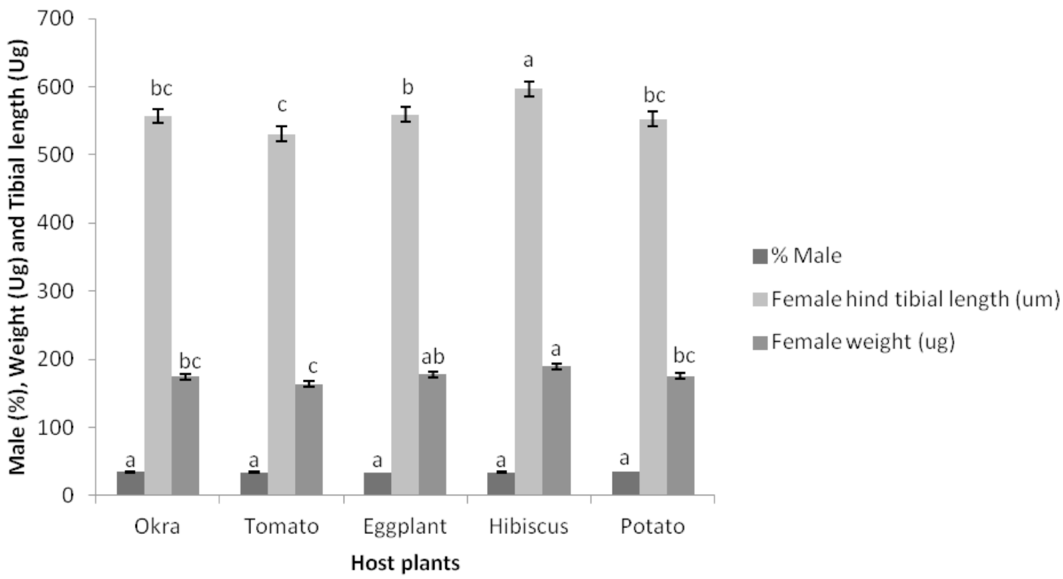

Fig. 1. Influence of *P. solenopsis* host plants on the fitness of *Aenasius bambawalei* under field conditions (no choice bioassays). Bars topped up by different litters within each parameter are significantly different at 5% level of probability.

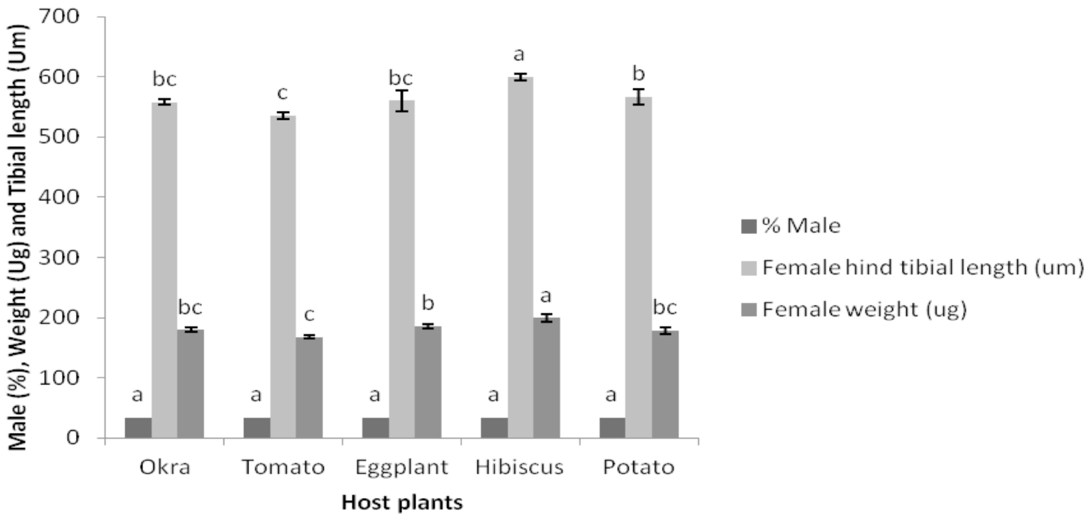

Fig. 2. Influence of *P. solenopsis* host plants on the fitness of *Aenasius bambawalei* under field conditions (choice bioassays). Bars topped up by different litters within each parameter are significantly different at 5% level of probability.

Table II.- Influence of *Phenacoccus solenopsis* host plants on the parasitism of *Aenasius bambawalei* under field conditions choice bioassays) during three consecutive weeks of parasitism (means[1] ± SE, n=10).

Host plants	Percent parasitism (weeks)			Percent parasitoid emergence (weeks)		
	1st	2nd	3rd	1st	2nd	3rd
Okra	65.0 ± 3.75ab	25.63 ± 1.12a	11.25 ± 1.25ab	88.55 ± 0.79a	90.17 ± 04.18a	91.67 ± 05.69a
Tomato	60.00 ± 2.83b	24.38 ± 1.46a	10.0 ± 1.02bc	88.54 ± 0.72a	88.17 ± 04.13a	90.00 ± 06.66a
Eggplant	51.88 ± 1.88c	19.38 ± 1.74b	8.13 ± 0.96c	86.69 ± 01.09a	87.67 ± 05.67a	90.00 ± 06.67a
Hibiscus	69.38 ± 2.54a	26.88 ± 2.29a	13.13 ± 0.63a	88.81 ± 02.35a	89.07 ± 03.97a	91.67 ± 05.69a
Potato	60.63 ± 2.80b	22.50 ± 1.02ab	10.0± 1.02bc	86.09 ± 01.94a	88.83 ± 04.71a	90.00 ± 06.66a

[1]Means in each column followed by the same letters are non significant at 5% level, using LSD test following ANOVA.

Multiple choice bioassays

During multiple-choice bioassays, *A. bambawalei* females could chose its mealybug host in relation to the host plant on which it was feeding. In that case, *A. bambawalei* were more attracted to mealybugs living on hibiscus and okra showed highest parasitism for the 3 weeks of parasitism while the lowest was recorded on mealybugs living on eggplant (Table II; $F_{4,45}$=5.32; p=0.0013 for the 1st week; $F_{4,45}$=3.9; p=0.0084 for the 2nd week and $F_{4,45}$=3.45; p=0.0153 for the 3rd week). No significant difference was obtained for % parasitoid emergence ($F_{4,45}$=0.68; p=0.6119 for the 1st week; $F_{4,45}$=0.07; p=0.9906 for the 2nd week and $F_{4,45}$=0.03; p=0.9978 for the 3rd week). The sex ratio also did not differ significantly between hosts living on different plants ($F_{4,45}$=0.03; p=0.9986). In contrast, the host plants influenced significantly the fitness of the parasitoid in terms of hind tibial length and body weight. In a similar trend that the previous experiment under no choice conditions, the female parasitoids coming from mealybugs reared on hibiscus exhibited a significantly longer hind tibia ($F_{4,45}$=04.70; p=0.0030) and body weight ($F_{4,45}$=06.77; p=0.0002) than the parasitoids coming from the mealybugs reared on the other plant species (Fig. 2).

Parasitism under laboratory conditions

No choice bioassays

In a similar trend that the results obtained from the aforementioned field study under no choice conditions, the results showed that the host plant influenced significantly the parasitism only at the third week of parasitism (Table III, $F_{4,45}$=0.17; p=0.9533 at the 1st week; $F_{4,45}$=0.89; p=0.4754 at the 2nd week and $F_{4,45}$=5.36; p=0.0013 at the 3rd week). However, the % parasitism was significantly lower at the 3rd week as compared to the previous weeks regardless of the host plant used. No difference was obtained for the % parasitoid emergence as well as for the sex ratio over the 3 weeks of parasitism (for % parasitoid emergence: $F_{4,}$

$_{45}$=0.75; p=0.5606 for the 1st week; $F_{4, 45}$=0.18; p=0.9487 for the 2nd week and $F_{4, 45}$=0.28; p=0.8882 for the 3rd week; for sex ratio: $F_{4, 45}$=0.09; p=0.9836). In contrast, the host plants influenced significantly the fitness of the parasitoid in terms of hind tibial length and body weight. The female parasitoids coming from mealybugs reared on hibiscus exhibited a significantly longer hind tibia ($F_{4, 45}$=07.36; p=0.0001) and body weight ($F_{4, 45}$=07.23; p=0.0001) than the parasitoids coming from the mealybugs reared on the other plants (Fig. 3).

Multiple host-plant choice tests

In a similar trend that the results obtained from the aforementioned field study under multiple choice conditions, female's parasitoid *Aenasius bambawalei* can easily distinguish its host (mealybug) on different plants through movement and foraging behavior inside nylon cloth. *A. bambawalei* were more attracted to mealybugs feeding on hibiscus and okra showing highest % parasitism for the 3 weeks of parasitism while the lowest was recorded on mealybugs feeding on eggplant (Table IV; F=8.69; p=0.0001 for the 1st week; $F_{4, 45}$=3.79; p=0.0097 for the 2nd week and F=5.07; p=0.0018 for the 3rd week). No significant difference was obtained for % parasitoid emergence ($F_{4, 45}$=0.10 p=0.9829 for the 1st week; $F_{4, 45}$=0.32 p=0.8638 for the 2nd week and $F_{4, 45}$=0.06 p=0.9930 for the 3rd week). The sex ratio did not differ also significantly between hosts feeding on different plants ($F_{4, 45}$=0.04; p=0.9973). In contrast, the host plants influenced significantly the fitness of the parasitoid in terms of hind tibial length and body weight. In a similar trend that the previous experiment under no choice conditions, the female parasitoids coming from mealybugs reared on hibiscus exhibited a significantly longer hind tibia ($F_{4, 45}$=3.64; p=0.0118) and body weight ($F_{4, 45}$=03.34; p=0.0177) than the parasitoids coming from the mealybugs reared on the other plant species (Fig. 4).

Table III.- Influence of *Phenacoccus solenopsis* host plants on the parasitism of *Aenasius bambawalei* under laboratory conditions (no choice bioassays) during three consecutive weeks of parasitism (means[1] ± SE, n=10).

Host plants	Percent parasitism (weeks)			Percent parasitoid emergence (weeks)		
	1st	2nd	3rd	1st	2nd	3rd
Okra	53.63 ± 2.05a	22.38 ± 1.51a	10.50 ± 0.46b	85.53 ± 0.88a	87.38 ± 01.45a	88.31 ± 01.58a
Tomato	53.38 ± 2.22a	20.88 ± 1.01a	9.13 ± 0.49b	86.62 ± 01.02a	88.80 ± 01.12a	89.15 ± 02.84a
Eggplant	51.75 ± 1.43a	19.88 ± 1.48a	8.88 ± 0.68b	86.95 ± 0.95a	87.45 ± 01.50a	91.21 ± 02.60a
Hibiscus	54.00 ± 2.49a	22.88 ± 1.31a	12.38 ± 0.57a	86.45 ± 0.69a	87.72 ± 01.19a	90.38 ± 01.95a
Potato	53.00 ± 2.17a	21.87 ± 1.15a	9.75 ± 0.67b	87.64 ± 0.85a	87.75 ± 01.48a	88.78 ± 02.09a

[1]Means in each column followed by the same letters are non significant at 5% level, using LSD test following ANOVA.

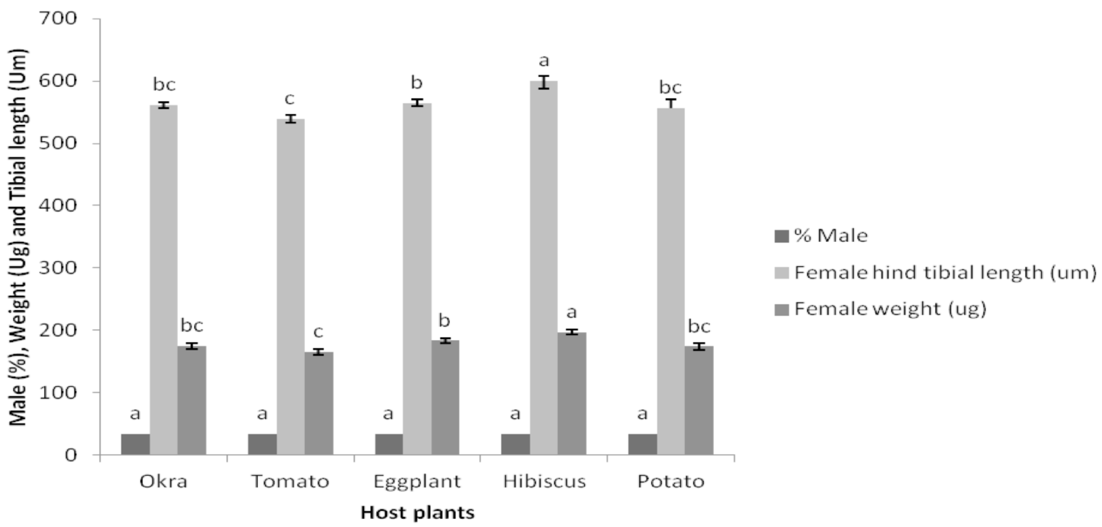

Fig. 3. Influence of *P. solenopsis* host plants on the fitness of *Aenasius bambawalei* under laboratory conditions (no choice bioassays). Bars topped up by different litters within each parameter are significantly different at 5% level of probability.

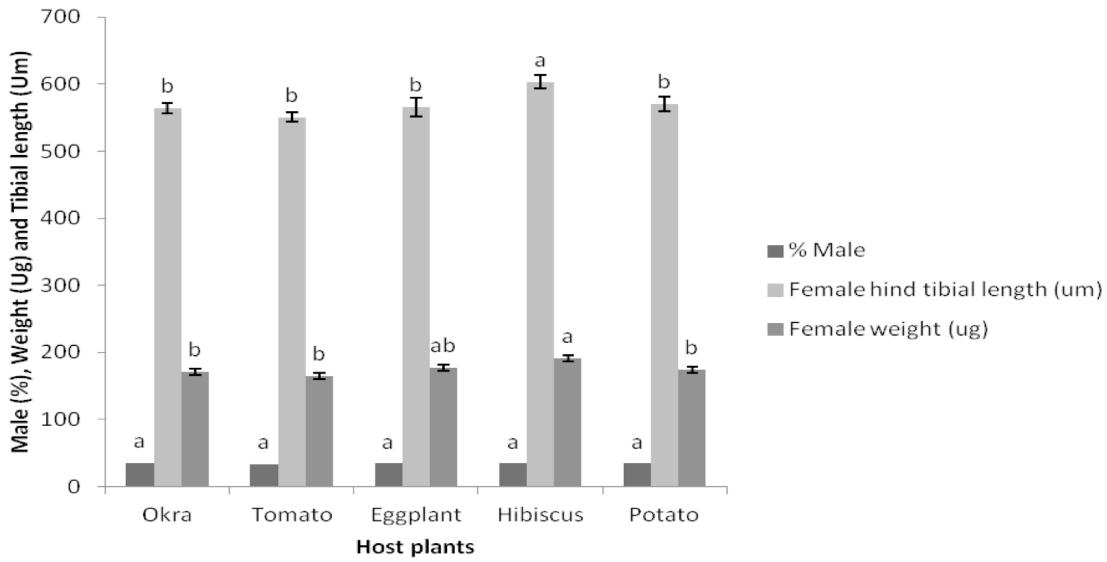

Fig. 4. Influence of *P. solenopsis* host plants on the fitness of *Aenasius bambawalei* under laboratory conditions (choice bioassays). Bars topped up by different litters within each parameter are significantly different at 5% level of probability.

Table IV: Influence of *Phenacoccus solenopsis* host plants on the parasitism of *Aenasius bambawalei* under laboratory conditions (choice bioassays) during three consecutive weeks of parasitism (means[1] ± SE, n=10).

Host plants	Percent parasitism (weeks)			Percent parasitoid emergence (weeks)		
	1st	2nd	3rd	1st	2nd	3rd
Okra	63.13 ± 2.71ab	26.25 ± 1.82b	13.75 ± 0.83ab	85.88 ± 03.55a	89.0 ± 3.72a	93.33 ± 04.44a
Tomato	61.25 ± 2.60b	24.38 ± 1.73b	11.88 ± 1.12bc	86.63 ± 1.52a	93.5 ± 3.34a	91.67 ± 05.69a
Eggplant	49.38 ± 2.54c	21.25 ± 1.91b	10.00 ± 1.02c	85.61 ± 1.71a	90.50 ± 3.91a	91.67 ± 05.69a
Hibiscus	68.13 ± 2.37a	31.88 ± 2.37a	15.63 ± 1.04a	87.29 ± 1.93a	89.07 ± 3.11a	93.33 ± 04.44a
Potato	53.75 ± 2.50c	26.25± 1.56b	13.13 ± 0.63ab	86.24 ± 0.97a	88.50 ± 3.88a	93.33 ± 04.44a

[1]Means in each column followed by the same letters are non significant at 5% level, using LSD test following ANOVA.

DISCUSSION

Plant species not only influence phytophagous insect but also their associated natural enemies (Arif *et al*., 2012). For example, host plants structure and morphology can strongly influence the location and acceptance ability of parasitoids for their hosts (Wang *et al*., 2013; Wang *et al*., 2009). In our study, the host plant on which *P. solenopsis* was feeding on, was significantly influencing the host acceptance by *A. bambawalei* in terms of parasitism. The plant used in this study exhibited very different morphology characteristics, like leaf structure and shape, number of trichomes per centimeter surface area and leaf thickness. Among the plant species used in our study, hibiscus exhibits very thin leaves and less number of trichomes as compared to the other plant species, probably helping the wasp to encounter more easily its host.

Moreover, plants provide generally chemical signals used as foraging cues by parasitic and predaceous arthropods (Godfray, 1994; Turlings *et al*., 1995). Apart from pheromones, the chemical compounds originating from herbivores are at most slightly volatile and can only be detected at close range (Vet and Dicke, 1992). Plant volatiles released in response to mechanical damage by herbivores, including green-leaf volatiles and constitutive secondary compounds, are known to be attractive to various parasitoids (Steinberg *et al*., 1993; Mattiaci *et al*., 1994). Volatiles released in response to herbivore feeding are generally reliable indicators of herbivore presence and can potentially bring parasitoids in close proximity to their hosts. In the present study, we observed that during multiple-choice conditions the female parasitoid

A. bambawalei could easily make a choice of its host according to the plant species on which it was feeding. These preferences for mealybugs feeding on hibiscus can be therefore attributed also to chemical cues more attractive to *A. bambawalei* than the chemicals emitted by the other infested plant species. This corroborated the variability of this parasitoid species efficiency according to the locality and the plants on which *P. solenopsis* is feeding observed by Arif *et al*. (2012) in Pakistan.

We recorded also in our study a higher number of *P. solenopsis* parasitized during the 1st week of parasitism, indicating a clear negative correlation between the parasitism and the age of the parasitoid. Ashfaq *et al*. (2010) reported that in case of *A. bambawalei* parasitism efficacy, a significant reduction in parasitism with an increase in the age of parasitoid was observed. Such observation were also reported by Bertschy *et al*. (2000) for another parasitoid species *Aenasius vexans* (Kerrich) that after emergence during the first 5 days this parasitoid had parasitized the greatest number of mealybug and after that the parasitizing efficacy of the *A. vexans* decreased drastically.

However, the differences of parasitism between plant species were only highlighted at the 3rd week of parasitism not before. The highest % of parasitism on hibiscus and okra particularly in 3rd week also suggested that the parasitoids on these plants can live long and also get more energy or nutritional needs for a better rate of parasitism on such plant species. It is well reported in the literature that plants supply direct resources for parasitoids and predators for their survival, fecundity, and the efficiency of parasitism and predation (Sirot and Bernstein, 1996; Consuelo *et al*., 2000). Moreover, it is observed that the absence or the incompatibility of direct food sources from plant can result in a reduced parasitizing efficiency by the parasitoids, spending more time to search for food first than for hosts searching and parasitism (Lewis and Tumlinson, 1998).

Some herbivores can use plant secondary chemicals in defense against their parasitoids, which ultimately caused the parasitoid encapsulation (Singer, 2001; Singer *et al*., 2004). Blumberg (1995) reported that a high incidence of encapsulation may also cause difficulties in mass rearing of parasitoids. Our results suggest that in the case of *A. bambawalei* larval encapsulation was not probably occurring since adult emergence rates from all mealybugs feeding on these five host plants species remained non significant.

Moreover, it is well documented in the literature that in most hymenopterous parasitoids the accurate assessment of the host suitability for offspring development is important since females are supposed to maximize their reproductive success by ovipositing on high-quality hosts and that the plants influence strongly through the hosts the development and performance of the third trophic level (Godfray, 1994). However, little is known on the influence of the host plant on sex allocation process of the parasitic wasps (Ode, 2006). In our study, it was clearly showed that the host plant species did not influence the sex ratio. This is in agreement with the works of Ashfaq *et al*. (2010), Arif *et al*. (2012) and Fand *et al*. (2011). In contrast, our study showed that the host plant species influenced significantly the fitness of *A. bambawalei* females expressed in terms of tibia length and body weight. The female wasps grew better on mealybugs fed on hibiscus and okra than on the hosts fed on the other plant species used in this study. These results are in parallel with Ode (2006) who reported that the host plant affects the parasitoid fitness by a variety of means, including survivorship, clutch size, body size, and/or fecundity and negative impacts on parasitoid fitness may occur when the developing parasitoid encounters the plant toxin in the hemolymph or tissue of its herbivorous host. Similarly, Ode (2006) and Mooney *et al*. (2012) reported that host quality and chemistry could influence the parasitoid performance, either directly through plant toxins or metabolites in the host's hemolymph or tissues, or indirectly via changes in host quality or size. Moreover, similarly Yang and Sadof (1995) reported that *Coleus* sp leaf variegation can affect the rate of fecundity, survivorship, and population growth of both the citrus mealybug, *Planococcus citri* (Risso) and its associated parasitoid *Leptomastix dactylopii* (Howard). In the same way, in another study, it was reported that the host quality or size is commonly correlated to the parasitoid fitness, especially in idiobiont parasitoids, whose offspring may depend on the quality and size of the host at the time of oviposition (Gols and Harvey, 2008; Fortuna *et al*., 2012).

CONCLUSION

The current study revealed a significant influence of the host plant species mostly on the % parasitism and the parasitoid fitness (expressed here in term of tibia length and body weight) where hibiscus was the most suitable host plant. The originality of this study was to show this using colonies of both host and parasitoid previously reared during 4 generations on each of the five plant species tested in this study. All these aspects explain well why the efficiency of this parasitoid is variable according to the locality and the plants on which *P. solenopsis* is feeding. In addition, this study allows us to recommend the use of hibiscus, *Hibiscus rosa sinensis,* in the mass rearing process of *A. bambawalei* for a biological control program to control *P. solenopsis*.

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Statement of conflict of interest

The authors declare no conflict of interest.

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