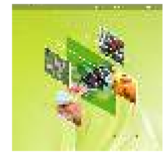
Pakistan Entomologist

Journal homepage: www.pakentomol.com



IMPACT OF MALE DENSITY AND FOOD SOURCES ON THE PROGENY DEVELOPMENT OF COTTON MEALYBUG, *PHENACOCCUS SOLENOPSIS* (HEMIPTERA: PSEUDOCOCCIDAE)

Muhammad Jalal Arif, Muhammad Dildar Gogi, Ahmad Nawaz, Muhammad Sufian and Amjad Majeed Pasha

Department of Entomology, University of Agriculture, Faisalabad, Pakistan.

ARTICLE INFORMATION

Received: October 03, 2015

Received in revised form: June 08, 2016

Accepted: June 15, 2016

***Corresponding Author**:

Muhammad Jalal Arif

E-mail: jalalarif807@yahoo.com

ABSTRACT

The study was conducted to determine the effect of different male densities (1:0, 1:1, 1:2, 1:3, 1:4 and 1:5 female: male) and different types food sources [Papaya (*Carica papaya*), Shoeflower (*Hibiscus rosa-sinensis*), Tomato (*Lycopercicon esculentum*), Potato (*Solanum tuberosum*), Brinjal (*Solanum melongena*), Pumpkin (*Cucurbita pepo*), Water melon (*Citrullus lanatus*), Silvery, Cucumber (*Cucumis sativus*) on the progeny development of *P. solenopsis*. The results revealed that the maximum eggs/ovisac were observed in Silvery (185.6) and minimum in shoeflower (99.5), tomato (98.5), brinjal (98.0) and cucumber (93.457). Similarly, maximum off-springs were observed on silvery (140.32) and minimum on shoeflower (81.6). Female feeding on brinjal and silvery supported maximum males' production (33.2-35.5 males/ovisac) and pumpkin administrated minimum males/ovisac (18); while, female feeding on shoeflower and tomato demonstrated maximum female production (40.2-45.4 females/ovisac) and feeding on potato and pumpkin exhibited minimum females production (20.2-21.9 females/ovisac). The maximum fecundity, hatchability and mortality were demonstrated in treatments where females were fed on the silvery and papaya as food source. The results of second experiment revealed that number of eggs/ovisac increased with increase in number of males. The maximum number of eggs/ovisac (29.3), offspring/ovisac (29.7), males/ovisac (8.7) and female/ovisac (15.2) were produced where male-to-female sex ratio was maintained at 5:1, 3:1, 1:1 and 3:1, respectively; whereas, maximum mortality was recorded at male-female sex ratio of 3:1 (32.6%), followed by 4:1 (31.7%). In conclusion, silvery and shoeflower proved suitable host plant as former supported more fecundity and hatchability and later supported more female production. However, male-female ratio revealed variable results.

Keywords: Male-density, Biological parameters, Hosts, *Phenacoccus solenopsis*, Laboratory studies

INTRODUCTION

Mealybug, *Phenococcus solenopsis* Tinsley (Hemiptera: Pseudococcidae) appeared first in Pakistan in 2005 and is now one of the main threatening pests on cotton crop. Mealybug, *P. solenopsis* became significantly invasive on cotton and other economic host plants in Pakistan from 2005 onwards. This damaging polyphagous pest spread rapidly to other cotton growing districts of the homeland and has become most devastating pest of cotton and other important plant hosts in subcontinent (Hodgson *et al*., 2008; Arif *et al*., 2009; 2013) and is the only specie that adopted hidden locality such as grass sheaths and galls and secrete mealy secretions (McKenzie, 1967). As compared to other insect pests, cotton mealy bug established more quickly due to its high fecundity and spread more easily through natural carriers like wind, birds, water and human beings. Cotton mealy bug is highly fecundative and multivolatine with a wide range of host plants including ornamentals, weeds, shrubs and cash crops (McKenzie 1967; Abbas *et al.,* 2010; Hameed *et al.,* 2012; Kedar *et al*., 2013; Vennila *et al*., 2013). This pest alone was responsible for the loss of about 0.2 million bales in 2007 (a bale weighs 375 lbs or 170 kg each) in Pakistan (Muhammad, 2007). Same year a huge loss of this cash crop was documented from the Indian Punjab due to this pest (Sharma, 2007).

Phenococcus solenopsis was inferred to infest a huge number of plants species including crops, vegetables, ornamental

Cite this article as: Arif, M.J., M.D. Gogi, A. Nawaz, M. Sufian and A.M. Pasha, 2016. Impact of male density and food sources on the progeny development of cotton mealybug, *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae). Pak. Entomol., 38(1):19-27.

plants and weeds (Arif *et al*., 2009; Abbas *et al*., 2010; Arif et al., 2013). It has many alternative hosts' plants including sunflower, vegetables, weeds, ornamentals etc. (Saini *et al*., 2009). It has been recorded on 154 plants species of about 53 families including 20 field and horticultural crops, about 45 ornamental plant species, 64 weed plants and 25 bushes and trees. Plants from the families Malvaceae, Solanaceae, Ficoidae, Amarantaceae, Asteraceae, Convolvulaceae, Euphorbiaceae, Verbenaceae and Zygophyllaceae are usually found as the most preferred hosts of this dangerous mealybug. Among these plants, *Hibiscus rosa sinensis*, *H. notabililis*, *Abutilon* spp. (Malvaceae), *Lantana camara* (Verbenaceae), *Withania somnifera* (Solanaceae), *Convolvulus arnesis* (Convolvulaceae), *Euphorbia prostrara*, *Croton sparciforum* (Euphorbiaceae) and *Achyranthes aspra* (Amaranthaceae) are the best plants for harboring this serious pest round the year. Huge infestations on *solanum melangena*, *S. nigrum, Datura metel* (solanaceae), *Xanthium strumarium* (Asteraceae), *Trianthema* spp. (Aizoaceae), *Chenopodium album* (Chenopodiaceae) and *Tribulus terrestris* (Zygophyllaceae) may help in the dispersal and spread of this economically serious pest during summer, whereas *Celosia argentia* (Amaranthaceae), *Calendula officinallis* (Asteraceae), *Cestrum nocturum* (Solanaceae) and *Asparagus spp.* (Liliaceae) serve as winter host plants of this pest. Other plants are either less preferred or the mealybug was observed incidentally in very small number for shorter periods of time. Its host range include *Aphelandra squarrosa* Nees (Zebra plant), *Achyranthes apera* Linn. (Devil horse whip, Puthkanda), *Amaranthus viridis* Linn (Pigweed, Jangli cholai), *Celosia argentea* Linn. (Cockscomb) *Digera arvensis* Forsk (Diagra, Tandla), *Daucus carota* Linn. (Carrot, Gajar), *Nerium indicum* Mill. (Oleander, Kanar), *Plumeria acutifolia* Poir (Gulchin), *Tabernaemontana coronaria* Willd. (Chandra), *Calotropis procera* R.Br. (Ak), *Ageratum conyzoides* Linn. (Ageratum), *Conyza banoriensis* L. (Cronquist Hairy fleabane, Loosan booti), *Calendula officinallis* Linn. (Gul-e-Asharfi), *Centaurea cyanus* Linn. (Cornflower, Pohla), *Chrysanthemum morifolium* Ramat (Chrysanthemum, Gul-e-Daudi), *Cichorium intybus* Linn. (Blue daisy, Chicory, Kashni), *Cnicus arvensis* Linn (Hoffm Cnicus, Laih), *Helianthus annuus* Linn. (Sunflower), *Launia nudicaudis* Less (Yellow spurge, Padhkal, Peeli dodhak), *Parphenium hysterophorus* L. (Lahori booti), *Sonchus oleraceous* Linn. (Dandelion), *Xanthium strumarium* Linn. (Cockleburr, Mohabbat booti), *Convolvulus arvensis* Linn. (Bindweed, Lehli), *Echinochloa colonum* Linn. (Deccan grass, Swanki), *Eleusine indica* Linn (Gaertin, Goose grass, Madhana grass), *Erogrostis minor* Host. (Eragrostis), *Anagallis arvensis* Linn. (Villy booti), *Capsicum frutescens* Linn. (Red chilly), *Cestrum diurnum* Linn. (Din ka raja), *C. nocturnum* Linn. (Night jasmine, Raat ki Rani), *Datura metel* Linn. (Thornapple, Datoora), *Lycopersicon esculentum* Linn. (Tomato), *Nicotiana plumbaginifolia* Viv. (Wild tobacco, Giddar tambaku), *N. tabacum* Linn. (Common tobacco), *Physalis alkakengi* Linn. (Mamola), *Solanum surratense* Burm (Arif *et al.,* 2009).

The knowledge of insect biology is necessary to understand its behavior of attack to crops. The total duration of nymphal instar of male is more than female on different host plants (Rashid *et al*., 2012). Cotton mealybug, *P. solenopsis* is an obligate amphimictic species and resorption of developed eggs fits the “wait to reproduce” oosorption hypothesis. Mating response and progeny development of mealybug also depend upon the male population available in the ecosystem. The impact of male density on the mating response of female and progeny development of the insect vary from insect species to species (Huang *et al*., 2013). Very little information on this aspect of *P. solenopsis* is available in reviewed literature. How individuals allocate resources to their male and female offspring is an important reproductive decision that can have significant fitness implications (West, 2009). For instance, females have been suggested to facultatively adjust their sex ratio to avoid competition among their offspring and in response to environmental factors influencing the relative fitness of male and female offspring. In mealybugs, adult males are winged and dispersive while adult females are sedentary and seldom move once adults (Gullan and Kosztarab, 1997). Females often settle close to where they hatched creating competition between related females for food and space. This competition could become intense since mealybugs, like many phloem-feeding Hemiptera, often form very dense colonies on their host plant. Varndell and Godfray (1996), therefore, expected females to produce relatively more males under high density, from the specific assumption that increasing density would increase competition between related females. Competition among relatives for resources, termed local resource competition (LRC), is expected to favor females that limit competition among offspring of the competing sex by producing more of the sex that avoids competition (in this case males) (Clark, 1978; Charnov *et al*., 1981).

Keeping in view the above-mentioned facts and lavunae, this research work was designed to achieve the following objectives: 1) to determine the effect of food resources on population of cotton mealy bug; and 2) to determine the effect of male density on population of cotton mealy bug.

MATERIALS AND METHODS

The experiment was conducted in IPM laboratory of Department of Entomology, University of Agriculture, Faisalabad. The study comprised of two experiments:

- Experiment-1: To investigate the impact of male density on progeny development of *Phenacocus solenopsis*
- Experiment-2: To investigate the impact of food sources on progeny development of *Phenacocus solenopsis*

Experiment-1: To investigate the impact of male density on progeny development of *Phenacocus solenopsis*

The experiment was conducted in the small plastic jars under controlled conditions. Six treatments including six female to male ratios (1:0, 1:1, 1:2, 1:3, 1:4 and 1:5) were used to determine the impact of male density on *Phenacoccus solenopsis.* The experiment was repeated thrice under CRD. The newly emerged females were released in the plastic jars with pumpkin as food. The predetermined population of male was released in the plastic jars with honey, sugar and water solution as male diet, till their death.

Experiment-2: To investigate the impact of food sources

on progeny development of *Phenacoccus solenopsis*.
The experiment was conducted in plastic jars containing 10 different hosts as food of female *Phenacoccus solenopsis*. The following ten host plants were used in this experiment as food source for female *P. solenopsis* Two individual of newly emerged females (along with two males of *P. solenopsis*) were released in each jar till the death of the female. The experiment was designed in CRD having three replications.

Sr. No.	Common Name of food sources	Scientific Name of food sources
1	Papaya	*Carica papaya*
2	Shoe flower	*Hibiscus rosa-sinensis*
3	Tomato	*Lycopercicon esculentum*
4	Potato	*Solanum tuberosum*
5	Brinjal	*Solanum melongena*
6	Pumpkin	*Cucurbita pepo*
7	Water melon	*Citrullus lanatus*
8	Silvery	*Dichondra Silver*
9	Cucumber	*Cucumis sativus*
10	Okra	*Abelmoschus esculentus*

DATA COLLECTION

For both of the above experiments, the data were collected on daily basis on number of offspring produced throughout the female life, number of female and male population emerged from the female, number of egg sacs produced, number of nymphs and the mortality of the newly emerged offspring.

Statistical Analysis
All the data regarding number of offspring produced throughout the female life, number of female and male population emerged from the female, number of egg sacs produced, number of nymphs and the mortality of the newly emerged offspring were subjected to ANOVA techniques and Tucky HSD test were used for comparing the means of significant treatments.

RESULTS

Impact of male density on various progeny development related parameters ***Impact of male density on number of ovisac produced by female P solenopsis throughout its life***
The analysis of variance for ovisacs produced by female throughout its life showed that effect of all treatments on density of ovisacs/female/life-span varied significantly (F value = 4.87 and P< 0.05) (Table 1). Maximum numbers of ovisacs/female/life-span were produced by the females in T_6 where 5:1 male-female sex ratio was maintained (29.3 ovisacs/female/life-span). The females in T_3, T_4 and T_5 where male-female sex ratio of 4:1 3:1 and 2:1 was maintained produced similar number of ovisacs/female/life-span (≈ 27-28 ovisacs/female/life-span). However, T_1 and T_2 where male-to-female sex-ratio of 1:1 and 0:1 was maintained produced approximately 24-25 ovisacs/female/life-span. These results reveal that male density had significant impact on the ovisacs/female/life-span of *P. solenopsis*. The number of ovisacs/female/life-span increased with increasing male density in the treatments. The ovisac production by female in its life-span in treatment having no male released confirmed that female also had potential to reproduce parthengenetically (Table 2).

Impact of male density on number of offspring produced by female P. solenopsis per ovisac
The analysis of variance for number of offspring produced by female per ovisac showed that effect of all treatments on number of offspring produced by female per ovisac varied significantly (F value = 7.87 and P< 0.05) (Table 1). Maximum numbers of offsprings per ovisac were produced by the females in T_4 where 3:1 male-female sex ratio was maintained (23.7 offsprings/female/ovisac), which was statistically similar to those numbers of offspring per ovisac produced by the females in T_3 (21.9 offsprings/female/ovisac) and T_2 (19.9 offsprings/female/ovisac) where male-female sex ratio of 2:1 and 1:1 was maintained. Likewise, females in T_1 T_5 and T_6 where male-to-female sex-ratio of 0:1, 4:1 and 5:1 was maintained, produced approximately 17.6, 18.5 and 19.6 offsprings/female/ovisac which were not only statistically similar with each other but also with T_3 (2:1 male-to-female sex ratio), except T_1 (0:1 male-to-female sex ratio). The minimum numbers of offsprings produced per ovisac by females in T_1 were significantly different from maximum offsprings/female/ovisac of T_4 where male-to-female sex ratio of 3:1 was maintained. These results reveal that male density had significant impact on the offsprings/female/ovisacs of *P. solenopsis*. The number of offsprings/female/ovisac increased with increasing male density from T_1 to T_4, however, a decreasing trend in

offsprings/female/ovisac was observed at male-to-female sex ratio higher than 3:1 (Table 2).

Impact of male density on number of male individuals produced by female P. solenopsis per ovisac

The analysis of variance for number of male offspring produced by female per ovisac showed that effect of all treatments on number of male offspring produced by female per ovisac varied significantly (F value = 3.86 and P < 0.05) (Table 1). Comparatively, maximum numbers of male offsprings per ovisac were produced by the females in T_2 and T_1, where 1:1 and 0:1 male-female sex ratio was maintained, respectively (8.7 male offsprings/female/ovisac), which were statistically similar to those numbers of male offspring per ovisac produced by the females in T_6 (8.6 male offsprings /female/ovisac), T_4(8.5 male offsprings/female/ovisac) and T_3 (8.5 male offsprings/female/ovisac) where male-female sex ratio of 5:1, 3:1 and 2:1 was maintained, respectively. Likewise, females in T_5 where male-to-female sex-ratio of 4:1 was maintained produced 7.6 male offsprings/female/ovisac which was statistically similar to T_3 (2:1 male-to-female sex ratio), T_4 (3:1 male-to-female sex ratio) and T_6 (5:1 male-to-female sex ratio) but different from T_1(0:1 male-to-female sex ratio) and T_2 (1:1 male-to-female sex ratio). These results reveal that male density had significant impact on the male offsprings/female/ovisacs of *P. solenopsis*. The number of male offsprings/female/ovisac exhibited negligible fluctuation with variation in male density (Table 2).

Impact of male density on number of female individuals produced by female P. solenopsis per ovisac

The analysis of variance for number of female offspring produced by female per ovisac showed that effect of all treatments on number of female offspring produced by female per ovisac varied significantly (F value = 7.1 and P < 0.05) (Table 1). Comparatively, maximum numbers of female offsprings per ovisac were produced by the females in T_4, where 3:1 male-female sex ratio was maintained, (15.2 female offsprings/female/ovisac), which was statistically similar to those numbers of female offspring per ovisac produced by the females in T_3 (13.5 female offsprings/female/ovisac), where male-female sex ratio of 2:1 was maintained. Likewise, females in T_2 (1:1 male-female ratio), T_6 (5:1 male-female sex ratio) and T_5 (4:1 male-female sex ratio) produced 11.2, 11.0 and 10.9 female offsprings/female/ovisac which were not only statistically similar with each other but also with T_3 (2:1 male-to-female sex ratio). The females in treatment T_1 (0:1 male-female ratio) produced 8.8 females offsprings/female/ovisac which exhibited statistical similarity to T_2 (1:1 male-female ratio), T_6 (5:1 male-female sex ratio) and T_5(4:1 male-female sex ratio); however was found statistically different from T_3 (2:1 male-female ratio) and T_4(3:1 male-female sex ratio). These results reveal that male density had significant impact on the female offsprings/female/ovisacs of *P. solenopsis*. The number of female offsprings/female/ovisac exhibited prominent fluctuation with variation in male density (Table 2).

Impact of male density on the mortality of P. solenopsis per ovisac

The analysis of variance for mortality of *P. solenopsis* per ovisac showed that effect of all treatments on mortality per ovisac varied significantly (F value = 42.4 and P < 0.05) (Table 1). Comparatively, maximum mortality was observed in T_4, where 3:1 male-female sex ratio was maintained (32.6%), which was statistically similar to the mortality in T_5 (31.7%), where male-female sex ratio of 4:1 was maintained. In T_6 (5:1 male-female ratio), T_3 (2:1 male-female sex ratio) and T_2 (1:1 male-female sex ratio), 27.9, 26.5 and 24.5% mortality per ovisac was observed, respectively, which were found statistically similar with each other. The minimum mortality of *P. solenopsis* per ovisac was observed in treatment T_1 (0:1 male-female ratio) (22.6%) which exhibited statistical similarity to T_2 (1:1 male-female ratio) (24.5%). These results reveal that male density had significant impact on the nymphal mortality/ovisacs (Table 2).

Table 1.

ANOVA for different progeny development related parameters of female *P. solenopsis* exposed to various male densities (Total degree of freedom = 17).

Progeny development related parameters	*df (a/b)*	SS	MSS	F-value	P-value
Ovisac per female (fecundity)	$5^a/12^b$	65.4520	13.0904	4.87	0.0115**
Numbers of off-springs produced per ovisac by each female	$5^a/12^b$	77.636	15.5272	7.87	0.0017**
Numbers of male off-springs produced per ovisac by each female	$5^a/12^b$	2.91867	0.58373	3.86	0.0257**
Numbers of female off-springs produced per ovisac by each female	$5^a/12^b$	76.238	15.2476	7.10	0.0026**
Nymphal mortality per ovisac	$5^a/12^b$	233.581	46.7162	42.4	0.0000**

df = degree of freedom; ^{a} = treatment degree of freedom; ^{b} = error degree of freedom; SS = Sum of squares; MSS = means Sum of squares; ** = highly significant at probability level of 5%

Table 2.

Progeny development related parameters (means±SE) of female *P. solenopsis* exposed to different male densities.

Treatments (? : ?)	Progeny development related parameters of *P. solenopsis*				
	Ovisacs per female (N)	Total off-springs per female per ovisac (N)	? off-springs per female per ovisac (N)	? off-springs per female per ovisac (N)	Nymphal mortality (%)
5 : 1 (T_6)	29.3±3.2^{A}	19.6±4.4^{BC}	8.6±1.2^{AB}	11.0±2.1^{BC}	31.9±5.5^{A}
4 : 1 (T_5)	28.3±4.2^{AB}	18.5±3.5^{BC}	7.6±0.99^{B}	10.9±2.0^{BC}	31.7±6.2^{A}
3 : 1 (T_4)	28.5±2.6^{AB}	23.7±5.1^{A}	8.5±1.4^{AB}	15.2±2.8^{A}	32.6±5.9^{A}
2 : 1 (T_3)	27.9±2.9^{AB}	21.9±3.6^{AB}	8.5±0.78^{AB}	13.5±2.6^{AB}	26.4±4.8^{BC}
1 : 1 (T_2)	25.2±1.8^{AB}	19.9±3.2^{ABC}	8.7±1.7^{A}	11.2±1.9^{BC}	24.5±4.1^{CD}
0: 1 (T_1)	24.1±1.9^{B}	17.6±2.9^{C}	8.7±1.4^{A}	8.8±0.98^{C}	22.6±3.9^{D}

The means in same column bearing same alphabets don't different significantly from each other at probability level of 5%

Impact of food sources on the progeny development of *Phenacoccus solenopsis*

Impact of different food sources on the fecundity of P. solenopsis

ANOVA parameters reveal that food sources fed on by female *P. solenopsis* had a significant effect on the fecundity (eggs/ovisac) as a probability value against the treatments (food sources) was less than 0.05 (P < 0.05) (Table 3). The maximum fecundity (185.7 eggs/ovisac) was demonstrated by the females which were fed on the silvery as food source for female *P. solenopsis*. The females which were fed on papaya exhibited 177.2 eggs/ovisac which was statistically similar with the fecundity of female *P. solenopsis* fed on silvery and potato. The females which were offered potatoes as food sources exhibited a fecundity of (170.9 eggs/ovisac). Water melon as a female food source explained (157.3 eggs/ovisac) in female *P. solenopsis* and was found statistically different from the fecundities of females which were offered with food sources other than water melon. Similarly, females fed on pumpkin as food source exhibited a fecundity of (132.6 eggs/ovisac) and was also found statistically different from the fecundities of females fed on food sources other than pumpkin. Tomato as food source for female *P. solenopsis* demonstrated a fecundity of (116.4 eggs/ovisac) which was found statistically different from the fecundities of females offered with food sources other than tomato. The females fed on shoe flowers exhibited a fecundity of (99.5 eggs/ovisac) followed by the fecundities of females offered with okra (98.5 eggs/ovisac), brinjal (98.0 eggs/ovisac) and cucumber (93.5 eggs/ovisac) which imposed statistically similar effects on the female fecundity of *P. solenopsis*; but imposed effects significantly different from those of all other food sources. The results reveal that silvery, papaya and potato plants were found comparatively more suitable female food plants as these plant species demonstrated higher numbers of eggs per ovisac (Table 4).

Impact of different food sources on numbers of offspring of P. solenopsis

ANOVA parameters reveal that food sources fed on by female *P. solenopsis* had a significant effect on the numbers of offspring produced/ovisac because a probability value of less than 0.05 (P < 0.05) was established for treatments (food sources) (Table 3). The maximum numbers of offsprings (140.3 offsprings/ovisac) were hatched out from the ovisac laid by the females which were fed on the silvery plants as food source for female *P. solenopsis*. The second highest numbers of offsprings (138.0 offsprings/ovisac) were hatched out from the ovisac laid by the females which were fed on water melon plants as food source which was found statistically similar with silvery and papaya plants. The females which were offered Papaya plants as food sources exhibited (132.6 offsprings/ovisac). Potato and pumpkin as a female food source explained (130.6 and 129.6 offsprings/ovisac) in female *P. solenopsis*, respectively and their impacts on offspring/ovisac were found statistically similar to that of papaya plant but different from that of others as food source. Similarly, females fed on tomato, cucumber and brinjal as food source produced (94.9, 91.0 and 88.6 offsprings/ovisac), respectively and were found statistically similar with each other as food sources. The females fed on shoe flower as food source produced (81.6 offsprings/ovisac); whereas females fed on okra produced (86.8 offsprings/ovisac); however, both food sources imposed a statistically similar effects on the offspring/ovisac production by female *P. solenopsis*. The results reveal that silvery, Papaya, water melon, potato and pumpkin plants were found comparatively more suitable female food plants as these plant species demonstrated higher hatchability and more production of offspring per ovisac. The rest of the plant species as female food source explained less hatchability of eggs inside the ovisac and demonstrated less number of offspring per ovisac (Table 4).

Impact of different food sources on the number of male off-springs produced by P. solenopsis

ANOVA parameters reveal that food sources fed on by female *P. solenopsis* had a significant effect on the number of produced males of *P. solenopsis* as a probability value against the treatments (food sources) was less than 0.05 (P < 0.05) (Table 3). The maximum numbers of males per ovisac (33.5 male offsprings/ovisac) were produced by the females which were fed on the brinjal as food source for female *P. solenopsis*. The females fed on silvery produced 33.2 male offspring/ovisac and was statistically similar to that which were produced by females fed on brinjal and tomato. The females which were fed on papaya produced 24.6 male offsprings/ovisac and were statistically similar with the number of male offsprings/ovisac produced by females fed on okra and potato. Water melon as a female food source explained 22.6 male offsprings/ovisac in female *P. solenopsis* and was found statistically similar with okra, papaya and potato but different from the number of male offsprings/ovisac of *P. solenopsis* which were offered on brinjal, silvery, tomato, cucumber, and shoeflower. Similarly, females which were fed on cucumber as food source produced 28.0 male offsprings/ovisac and was also found statistically similar to the number male-offspring/ovisac of those females which were fed on tomato, shoeflower, okra, papaya and potato but different from the numbers of male-offspring/ovisac of those females which were fed on rest of the female food sources. Tomato as food source for females of *P. solenopsis* demonstrated 29.6 male-offsprings/ovisac which was found statistically similar to brinjal, silvery, cucumber and shoeflower as female food sources but different from rest of the food sources. The females which were fed on cucumber produced 28.0 male-offsprings/ovisac followed by shoeflower (27.9 male offsprings/ovisac), okra (24.6 male offsprings/ovisac) and papaya (24.6 male offsprings/ovisac) which imposed statistically similar effects on the number of males of *P. solenopsis*; but imposed effects significantly different from rest of all other food sources. The minimum numbers of males per ovisac (18.5 male offsprings/ovisac) were produced by the females which were fed on the pumpkin as food source and were found statistically similar with water melon. The results reveal that silvery, brinjal and tomato plants were found comparatively more suitable female food plants as these plant species demonstrated higher numbers of male offsprings/ovisac (Table 4).

Impact of different food sources on the number of female off-springs produced by P. solenopsis

ANOVA parameters reveal that food sources fed on by female *P. solenopsis* had a significant effect on the number of female-offsprings/ovisac as a probability value against the treatments (food sources) was less than 0.05 (P < 0.05) (Table 3). The maximum numbers of female-offsprings per ovisac (33.2 female-offsprings/ovisac) were produced by the females which were fed on the shoeflower as female food source. The females which were fed on cucumber produced 24.1 female-offsprings/ovisac which was statistically similar with the number of females-offsprings/ovisac produced when females were fed on all food sources except shoeflower and tomato. The females which were offered tomato as food sources produced 32.2 female-offsprings/ovisac which were similar to that of females fed on shoeflower but different from rest of the food sources. Papaya as a female food source explained 27.0 female-offsprings/ovisac produced by female *P. solenopsis*. The females fed on brinjal produced 24.1 female-offsprings/ovisac followed by those females offered with watermelon (23.1 female-offspring/ovisac), okra (22.6 female-offsprings/ovisac), pumpkin (21.9 female-offsprings/ovisac) and potato (20.2 female-offsprings/ovisac) which imposed statistically similar effects on the number of females-offspring/ovisac produced by female of *P. solenopsis*; but imposed effects significantly different from those of all other food sources. The minimum numbers of females per ovisac (20.2 female-offsprings/ovisac) were produced by the females which were fed on the potato as food source for female *P. solenopsis*. The results reveal that shoe flower and tomato plants were found comparatively more suitable female food plants as these plant species demonstrated higher numbers of female-offsprings per ovisac (Table 4).

Impact of different food sources on the mortality of P. solenopsis

ANOVA parameters reveal that food sources fed on by female *P. solenopsis* had a significant effect on the mortality (P < 0.05) (Table 3). The maximum mortality (55.3%) was demonstrated by the females which were fed on the silvery as food source for female *P. solenopsis*. About 46% mortality in nymphal stages was observed when females were fed on water melon which was statistically similar with the mortality of female *P. solenopsis* fed on cucumber, pumpkin, okra, brinjal, shoeflower and tomato. The females which were offered potatoes as food sources exhibited 47.8% nymphal mortality which was statistically similar to that recorded when females were fed on papaya (51.3% nymphal mortality). Similarly, females fed on shoeflower as food source exhibited 42.8% nymphal mortality and was also found statistically different from the mortalities of females fed on potato, papaya and silvery. Brinjal as food source for female *P. solenopsis* demonstrated a 44.1% nymphal mortality which was found statistically different from the mortalities of females fed on potato, papaya and silvery. When females were fed on cucumber, 45.8% nymphal mortality was recorded followed by the nymphal mortalities when females offered with pumpkin (45.8%) okra (45.7%), brinjal (44.1%) shoeflower (42.8) and tomato (42.5%) which imposed statistically similar effects on the nymphal mortality; but imposed effects significantly different from those of potato, papaya and silvery. The minimum mortality (42.5%) was recorded when females were fed on the tomato as food source for female *P. solenopsis*. The results reveal that silvery, papaya and potato plants were found comparatively unsuitable female food plants as there plant species demonstrated higher numbers of mortality per ovisac (Table 4).

DISCUSSION

The present research was conducted to determine the effect of male density as well as of various host plants on different progeny development related parameters of mealybug i.e. eggs per ovisac, number of hatched nymphs, number of males

Table 1.

ANOVA for different progeny development related parameters of female *P. solenopsis* fed on various host plants (Total degree of freedom = 29).

Progeny development related parameters	*df (a/b)*	SS	MSS	F-value	P-value
Number of eggs per ovisac (fecundity)	$9^a/20^b$	36378.4	4042.5	444	0.0000**
Numbers of off-springs produced per ovisac by each female	$9^a/20^b$	16187.2	1798.57	343	0.0000**
Numbers of male off-springs produced per ovisac by each female	$9^a/20^b$	619.906	68.8785	23.8	0.0000**
Numbers of female off-springs produced per ovisac by each female	$9^a/20^b$	508.797	56.5330	25.0	0.0000**
Nymphal mortality per ovisac	$9^a/20^b$	417.760	46.4178	19.8	0.0000**

df = degree of freedom; ^{a} = treatment degree of freedom; ^{b} = error degree of freedom; SS = Sum of squares; MSS = means Sum of squares; ** = highly significant at probability level of 5%

Table 2.

Progeny development related parameters (means±SE) of female *P. solenopsis* fed on various host plants.

Host plant	Progeny development related parameters of *P. solenopsis*				
	Eggs per ovisac (fecundity) (N)	Total off-springs per female per ovisac (N)	? off-springs per female per ovisac (N)	? off-springs per female per ovisac (N)	Nymphal mortality (%)
Silvery	185.7±19.6^{A}	140.3±10.8^{A}	33.1±5.4^{A}	27.2±4.9^{B}	55.3±8.3^{A}
Papaya	177.2±16.6^{AB}	132.6±10.1^{BC}	24.5±3.2^{CD}	26.9±4.3^{BC}	51.3±7.9^{AB}
Potato	170.9±15.8^{B}	130.5±9.8^{C}	24.2± 3.1^{CD}	20.2±2.5^{D}	47.8±7.4^{BC}
Water Melon	157.3±14.9^{C}	138.0±9.5^{AB}	22.6±3.9^{DE}	23.0±3.6^{BCD}	46.2±7.1^{CD}
Pumpkin	132.6±13.7^{D}	129.6±9.0^{C}	18.0±2.2^{E}	21.9±2.9^{D}	45.7±6.8^{CD}
Tomato	116.4±12.8^{E}	94.9±8.6^{D}	29.6±5.1^{AB}	32.2±5.5^{A}	42.4±5.6^{D}
Shoe Flower	99.5±11.9^{F}	81.6±8.2^{F}	27.9±4.8^{BC}	33.1±5.8^{A}	42.7±5.9^{D}
Okra	98.5±11.5^{F}	86.8±7.9^{EF}	24.64.1^{CD}	22.6±3.0^{CD}	45.7±6.5^{CD}
Brinjal	98.0±11.1^{F}	88.6±7.5^{DE}	35.5±6.1^{A}	23.7±3.9^{BCD}	44.1±6.1^{CD}
Cucumber	93.5±10.9^{F}	91.0±7.4^{DE}	28.0±4.9^{BC}	24.1±4.1 ^{BCD}	45.8±6.6^{CD}

The means in same column bearing same alphabets don't different significantly from each other at probability level of 5%

and females produced and mortality of offspring. In these experiments, male density as well as host plants had significant and variable effects on different progeny development related parameters of female *P. solenopsis.* The host plant related results are highly in consistent with those of Sana-Ullah et al. (2011) who also concluded that host plants had variable effects on the biological parameters of cotton mealybug. The maximum fecundity (185.7 eggs/ovisac) was demonstrated by the females which were fed on the silvery as food source for female *P. solenopsis*. The females which were fed on papaya exhibited 177.2 eggs/ovisac which was statistically similar with the fecundity of female *P. solenopsis* fed on silvery and potato. These results are not in agreement with those of Arif et al. (2012) who reported highest population development records on Chinese-rose. The variation in the results may be attributed to the difference in the experimental protocol of Arif et al. (2012). They had survey the population of various instars of *P. solenopsis* on various host plants in the field condition; whereas, present study was carried out under laboratory conditions. Regarding egg production per ovisac, silvery. Papaya and potato plants were found comparatively more suitable female food plants as there plant species demonstrated higher numbers of eggs per ovisac. The maximum numbers of offsprings (140.3 offsprings/ovisac) were hatched out from the ovisac laid by the females which were fed on the silvery plants as food source for female *P. solenopsis* followed by those laid by the females fed on water melon (138.0 offsprings/ovisac) and papaya (132.6 offsprings/ovisac). The maximum numbers of males per ovisac (33.5 male offsprings/ovisac) were produced by the females which were fed on the brinjal as food source for female *P. solenopsis*; while The minimum numbers of males per ovisac (18.5 male offsprings/ovisac) were produced by the females which were fed on the pumpkin as food source and were found statistically similar with water melon. The maximum numbers of female-offsprings per were produced by the females which were fed on the shoeflower (33.2 female-offsprings/ovisac) and tomato (32.2 female-offsprings/ovisac) as female food source; while the minimum numbers of females per ovisac (20.2 female-offsprings/ovisac) were produced by the females which were fed on the potato as food source for female *P. solenopsis*. These results reveal that shoe flower and tomato plants were found comparatively more suitable female food plants as these plant species demonstrated higher numbers of female-offsprings per ovisac. The maximum mortality (55.3%) was demonstrated by the females which were fed on the silvery as food source for female *P. solenopsis*. So regarding nymphal mortality, silvery proved poor food souce for *P. solenopsis*.Silvery, papaya and potato plants were found comparatively unsuitable female food plants as these plant species demonstrated higher numbers of mortality per ovisac; whereas brinjal (44.1%), shoeflower (42.8%) and tomato (42.5%) proved comparatively suitable food source for female for *P. solenopsi*. The host plant specific variation in progeny development related parameters of mealybug as observed in present study on different plant species may be accredited to deficiency of specific growth promoting nutritional components or access of growth inhibiting chemical in one and other plant species observed in present study. Earlier reporters (Korndorfer, 2004; Goussain *et al.*, 2005; Chau and Heinz, 2006; Sarfraz *et al*., 2009; Sana-Ullah et al., 2011; Arif et al., 2012; 2013) also reported the same reason for variable influences of plant species on the biological parameters of different insects. These plant species based chemicals were not explored in present study and are needed to be identified for investigating the root-cause of such variation.

Male-biased sex ratio has significant effects on the mating behavior as well as on other biological parameters and subsequent fitness of females. The number of ovisacs/female/life-span increased with increasing male density in the present study. Maximum numbers of ovisacs/female/life-span were produced by the females in treatment where 5:1 male-female sex ratio was maintained (29.3 ovisacs/female/life-span). The number of males in sex ratio of 5:1 may be responsible for an enhanced competition among males for mating with single female and ultimately more chances of delivering sperms into female reproductive tracts and their storage in spermatheca for periodical fertilization of eggs as described by Carrillo et al. (2011). The ovisac production by female in its life-span in treatment having no male release confirmed that female also had potential to reproduce parthengenetically. Maximum numbers of off-springs per ovisac were produced by the females exposed to 3♂:1♀ sex ratio (23.7 off-springs/female/ovisac). The number of total off-springs as well as of male and female off-springs per ovisac increased with increasing male density from 0♂:1♀ to 3♂:1♀, however, a decreasing trend in these parameter was observed at male-to-female sex ratio higher than 3:1 i.e. 4♂:1♀ and 5♂:1♀. The higher number of off-springs as well as male and female progeny per ovisac per female at medium male-biased sex ration indicate that progeny development is not completely dependent on the male biased sex ratio rather is supported by less male-biased sex-ratio maintained in the experiment. This also indicates that females of *P. solenopsis* in less male competition for mating had better chances to develop ecologically required and conducive progeny in the ecosystem. The results of present study also reveal that higher nymphal mortality was observed in treatments where sex ratios of 3♂:1♀, 4♂:1♀ and 5♂:1♀ were maintained (31.7-32.6%) as compared to sex ratios of 2♂:1♀, 1♂:1♀ and 0♂:1♀ (22.6-26.4%). These results cannot be compared or contradicted as literature reviewed does not provide any information regarding the effect of male-biased sex ratio on the progeny development related parameters of female *P. solenopsis*. However some work of researchers who worked on insects other than *P. solenopsis* demonstrates similar results. For example, Carrillo et al. (2011) quantified how a male-biased operational sex ratio (OSR) (1:1, 2:1, or 5:1 male to female) affected the size of a female's first egg clutch and her offspring's survivorship in the housefly, *Musca domestica*. They reported that a male-biased OSR increased female fitness, females laid more eggs in their first clutch and had increased offspring survivorship at a 2:1 and 1:1 OSR, as compared to 5:1 male to female OSR. These results confirm the results of present study. In conclusion, the progeny development related parameters of female *P. solenopsis* is affected by both the host plants and male-biased sex ratio and these information should be considered for mass rearing *P. solenopsis* in the laboratory.

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