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Life table of *Phenacoccus solenopsis* Tinsley (Pseudococcidae: Hemiptera) on various phenological stages of cotton

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A study of the life table of *Phenacoccus solenopsis* Tinsely on cotton (*Gossypium hirsutum* L.) for two constitutive seasons at Entomological Farm, Punjab Agricultural University (PAU) Ludhiana revealed that among three phenophases (vegetative, flowering and maturation stage), gross reproductive rate (GRR), net reproductive rate (Ro), intrinsic rate of increase (rm), precise value of rm and finite rate of increase (λ) were maximum (329.83 and 349.10, 65.29 and 278.46, 0.169 and 0.242, 0.183 and 0.246, 1.184 and 1.274) at vegetative stage during 2008 and 2009, respectively. The total life cycle was completed in 32 days at vegetative stage while took maximum (39.00) days at maturation stage. During 2008, apparent mortality (100qx) was maximum (74.33 and 77.31%) at vegetative and flowering, respectively. Survival rate (Sx) was (0.26 and 0.23) in second instar at vegetative and flowering stage, whereas, at maturation stage the corresponding values for apparent mortality and survival rate were 40.69 and 0.59 in third instar. During 2009, maximum apparent mortality (76.35 and 56.91) and minimum survival rate (0.24 and 0.43) were recorded in adults at vegetative and maturation stage respectively. Heavy rainfall, *Aenasius* sp. (Hymenoptera: Encyrtidae) and *Coccinella* sp (Coleoptera: coccinellidae) contributed maximum mortality at vegetative and flowering stage, while rain fall and low temperature were major factors for mortality during maturation stage. The study suggested that *P. solenopsis* population is more affected by the biotic and abiotic factors in the vegetative stage. Therefore, the application of control measures at this stage could be drastically further reduces the population and thus prevents the buildup of population at later in the season.

Key words: Life table, *Phenacoccus solenopsis*, phenological stages, net reproductive rate (Ro), finite rate of increase (λ), intrinsic of increase (rm).

INTRODUCTION

Phenacoccus solenopsis Tinsley (Hemiptera: Pseudococcidae) had emerged as a major threat to cotton, vegetables and fruits in the world, causing huge losses (779.43 US$/ha) and reduced average seed cotton yield by 44% (Dhawan et al., 2007). *P. solenopsis* had caused 14% loss to cotton crop during 2005 in Pakistan (PWQCP, 2005). *P. solenopsis* originally reported on ornamentals and fruit crops in New Mexico (Tinsley, 1898).

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Then it spread to other parts of world like Caribbean and Ecuador (Ben-Dov, 1994), Chile (Larraín, 2002), Argentina (Granara de willink, 2003), Brazil (Culik and Gullan, 2005), Pakistan and India (Hodgson et al., 2008), China (Wang et al., 2009; Wu and Zhang, 2009), Sri Lanka (Prishanthini and Laxmi, 2009) and Australia (Admin, 2010). In India, *P. solenopsis* was predominant mealy bug infested cotton in Andhra Pradesh, Gujarat, Haryana, Maharastra, Rajsthan and Tamil Nadu (Nagrare et al., 2009). With the introduction of a fortuitously parasitoids, *Aenasius bambawali* Hayat (Hymenoptera : Encyrtidae) in India (Gautam et al., 2009; Hayat, 2009; Pala and Saini, 2010) and *Aneasius* sp. *Longiscapus* (Hymenoptera: Encyrtidae) in Pakistan (Bodlah et al., 2010) in combination with the already established IPM tactics, seemed to manage the mealy bug population.

Despite this biological and chemical control, the risk of spreading *P. solenopsis* remains high due to its polyphagous nature and high fecundity. Some other crops that are most susceptible to attack of *P. solenopsis* are cotton, *Trianthema monogyna* L. (*Shanti or itsit*), *Xanthium strumarium* L. (*gutputna*), *Achyranthus aspera* Linn. (*puthkanda*), ornamental plant (*Hibiscus rosa-sinensis* L.), okra, tomato, brinjal and chilli (Tanwar et al., 2008). Scientists at the National Centre for Integrated Pest Management, New Delhi have reported the Spatio-temporal distribution of host plant of *P. solenopsis* in India. Based on the report, the *P. solenopsis* had spread all over India (South > Centre >North region) (Anonymous, 2010).

P. solenopsis feed on 154 species of field vegetables, ornamental plants and weeds. Four parasitoid species and four predator species have reported against *P. solenopsis*. Some of these natural enemies such as *Aenasius* sp and *Cryptoleamus montrozieiri* (Coleoptera: coccinellidae), *Coccinella septumpuntata* have reported, identified and used to control *P. solenopsis*. Because of the polyphagous nature of *P. solenopsis*, researchers used different host plants for the study of biology (David et al., 2009; Abbas et al., 2010; Sana-Ullah et al., 2011). The variations in the methodologies complicated the efforts in estimating the life table parameter of *P. solenopsis*. Certain chemicals belongs to organophosphates (Profenophos, Acephate, etc), Carbaryl group (Sevin, Hexavin, etc.) and IGR's (Buperofezin) gave effective control of this pest (Anonymous, 2011).

Although number of chemicals and biological control agents are effective against cotton mealy bug (*P. solenopsis).* Parthenogentic reproduction of this pest can give birth to some young ones which may act as biotypes of this pest and may lead to resistance against these insecticides and biological control agents. Therefore, there is need to investigate the life table parameters of *P. solenopsis* and identification of the ecological factors (including both biotic and abiotic factors like predators, parasitoids, rainfall, relative humidity, etc.) associated with this pest as no such factors are reported prior to this study. This investigation presents concise information on the life table of *P. solenopsis* conducted on cotton (*Gossypuim hirsutus* L.) at three stages (vegetative, flowering and maturation stage). We determined the life table parameters, age-schedule of survival (lx), gross reproductive rate (GRR) (∑mx), net reproductive rate (R_o), mean length of generation (T), intrinsic rate of increase (rm), finite rate of increase/ day (λ) and doubling time (DT) of *P. solenopsis* under natural conditions. The main objective of this study is to provide a better understanding of life table of *P. solenopsis,* and to provide information about the favorable phenological stage for development and prediction of *P. solenopsis* distribution.

MATERIALS AND METHODS

Maintenance of insect colonies

Nymphs and adults of *P. solenopsis* were collected from different host and non-host plants in cotton fields of Southern region of Punjab State and from the University fields. These stages of *P. solenopsis* were maintained and mass multiplied on the various hosts (Congress grass, Gutputna, *Hibiscus* sp. and cotton) in earthen pots under screen house (4 × 3× 2 m) of 20 cm square mesh size at Entomological Farm, Punjab Agricultural University (PAU), Ludhiana. These hosts were selected for mass multiplications due to their preference by *P. solenopsis*. From these colonies, gravid females of *P. solenopsis* were transferred to cotton (RCH 134) plants for conditioning (3 to 4 days) in another screen house of same dimensions, so that of *P. solenopsis* adapt to the cotton plant and then produce the offspring /ovisacs on cotton plant. Colonies of *P. solenopsis* on cotton plants were used in experiments.

In winter, the colonies of *P. solenopsis* were reared on cuttings of tender parts of *Hibiscus* sp. in battery jars in the laboratory. The old cuttings replaced with newer when required. Temperature was control by using electrical heater to provide better condition for development and survival of *P. solenopsis*. Prior to the oncoming of main season (April to December), *P. solenopsis* were transferred to the cotton plant for conducting the experiments.

Methodology adopted

Seeds of cotton hybrid RCH 134 were procured from Rasi Seed Pvt. Ltd. Madhya Pradesh, India, and were sown in the 10 × 10 m^2 plots with three replication in randomized design at Entomological Research Farm, PAU, Ludhiana during 2008 and 2009 by following recommended guidelines for cotton cultivation (Anonymous, 2008). The experiments were conducted at three different phenophases that is, vegetative, flowering and maturation stage during June- mid July, mid-July - August and September – October, respectively, in both the years. *P. solenopsis* feed on the apical portion of cotton plant, thus the crawlers released on the upper canopy. Ten plants have tagged in each plot; hence thirty plants were used for one phenophase of the cotton crop to record the data. Ten newly hatched crawlers were collected from the insect colonies and transferred on the tagged cotton plants. Crawlers on each plant represented a cohort and each plant was act as replicate in the experiment under field conditions. Each plant and cohort has observed after 24 h and data on the life table parameters recorded. The presence of exuviae indicated the successful development from one instar to another. Various biotic (predators and

Table 1. Effect of different phenophases on the life table parameters of *P. solenopsis* on cotton (RCH 134).

Parameter	Vegetative stage		Flowering stage		Maturation stage	
	2008	2009	2008	2009	2008	2009
Gross reproductive rate(GRR) (∑mx)	329.83	349.10	328.65	327.81	231.17	246.54
Net reproductive rate (R_o = ∑lxmx)	65.29	278.46	18.69	28.68	79.20	72.76
Mean length of generation (T=∑ $l_x.m_x/R_o$)	24.51	23.23	27.00	28.86	30.05	29.94
Intrinsic rate of increase ($r_m = \log_e R_O/T$)	0.169	0.242	0.108	0.116	0.145	0.143
Precise value of r_m ($\sum e^{7-rmx}$. lxmx = 1097)	0.183	0.246	0.111	0.117	0.148	0.145
Finite rate of increase/ day ($\lambda=e^{rm}$)	1.184	1.274	1.114	1.123	1.156	0.154
Doubling time (DT= loge 2 /rm)	4.10	2.86	6.42	5.98	4.78	4.84

parasitoids) and abotic (rainfall, temperature and R.H.) factors were recorded to know that which factors are responsible for the mortality of *P. solenopsis* under field conditions.

Life table analysis

The effect of three phenophases (vegetative, flowering and full bloom) on the population growth and age structure of *P. solenopsis* was determined by assessing different life table parameters. Data measured on the survival and reproduction were used to estimate l_x (age-schedule of survival) and m_x (age-schedule of female birth). Age-specific survival is the fraction of initial cohort alive at age x, while age–schedule of female birth was the mean number of females produced by each female at a pivotal age in days (x). The formulae for estimating life table parameters of female *P. solenopsis* at each phenophase were (Atwal and Bains, 1974).

Gross reproductive rate (GRR) = ∑mx, Net reproduction rate (R_0) = ∑ lx mx, Mean length of generation (T) = ∑ x lx mx / R_o, Doubling time (DT) = $\log_e$ 2 / rm, Intrinsic rate of increase (rm) = $\log_e R_o$ / T, Finite rate of increase (λ) = e^{rm}

To calculate the precise value of rm, we followed Southwood (1978) graphical method by using the equation mentioned below:

$\sum e^{(7-rmx)}$. (lxmx) = 1097

Along with life table parameters, data on biotic (natural enemies) and abiotic (weather conditions) were also recorded. In the beginning, 300 nymphs used and then with the passage of time the mortality assessed along with the cause of death. The different observations recorded were (Atwal and Bains, 1974) pivotal age (x), number of individuals in the beginning (lx), number of individuals died (dx), factors responsible for death (dxf). Based on these observations, apparent mortality (100qx) and survival rate (Sx) were computed by using formula given below:

Apparent mortality (100qx) = dx/lx × 100

Survival rate (Sx) = lx of subsequent stage / lx of particular stage

RESULTS

The life table parameters of *P. solenopsis* show clear cut differences at three phenophases viz. vegetative, flowering and maturation stage (Table 1). Gross reproductive rate (GRR) was maximum (329.83 and 349.10) at vegetative stage followed by flowering stage (328.65 and 327.80) and minimum (231.17 and 246.54) at maturation stage during 2008 and 2009, respectively. Same trend was observed in finite rate of increase (λ) with corresponding values 1.184 and 1.274, 1.114 and 1.123, 1.156 and 0.154 at vegetative, flowering and maturation stage during both seasons, respectively. Maximum (65.29 and 278.46) net reproductive rate (R_o) and intrinsic rate of increase (rm) (0.169 and 0.242) was recorded at vegetative stage followed by maturation stage and minimum (18.69 and 28.68) net reproductive rate was recorded at flowering stage. Similar results were recorded in precise value of rm as in net reproductive rate. Mean length of generation (T) increased as the cotton phases goes towards maturation stage. Maximum mean length of generation (30.05 and 29.94 days) was observed at maturation stage followed by flowering stage (27.00 and 28.86 days) and minimum (24.51 and 23.23 days) at vegetative stage in 2008 and 2009, respectively. The minimum (4.10 and 2.86) doubling time (DT) was recorded at vegetative stage and maximum (6.42 and 5.98 days) at flowering stage during respective years of study. Age specific survival (lx) of *P. solenopsis* is presented in Figures 1 and 2. Quite similar results were obtained during both years. Pivotal age (x in days) to complete the life cycle was least (approx. 32.5 days) at vegetative stage, while, maturation stage took maximum (approx. 39.5 days) time to complete one generation. This difference in the pivotal age may be due to hardening of the plant parts as it reaches to maturity. Precise value of rm was calculated only at vegetative stage as the intrinsic rate of increase has maximum value in this stage. The corresponding values for precise rm were 0.183 and 0.246 during 2008 and 2009, respectively (Figure 3).

During 2008, heavy rainfall (199 mm) responsible for 74.33% mortality in second instar nymphs developing on cotton plants in vegetative stage, while no substantial mortality in other developmental stages (Table 2). At flowering stage, heavy rainfall (161.8 mm), Aenasius sp. and Coccinella sp contributed 77.31% mortality in second instar nymphs, while it was 71.21% in the third instar. At maturation stage, the highest percent mortality (40.64%) observed in the second instar nymphs due to heavy rainfall (64.2 mm) coupled with high relative humidity

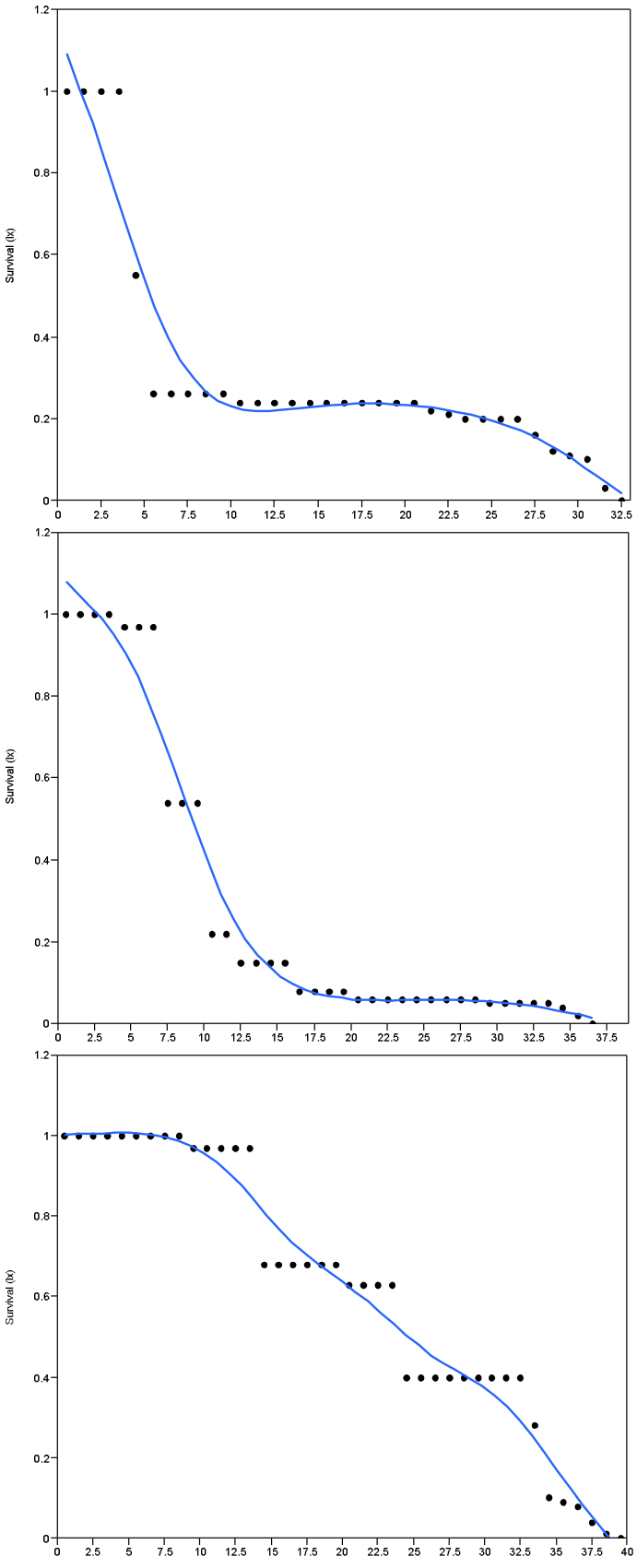

Figure 1. Age- specific survival (lx) of *P. solenopsis* at different phenophases of cotton during 2008.

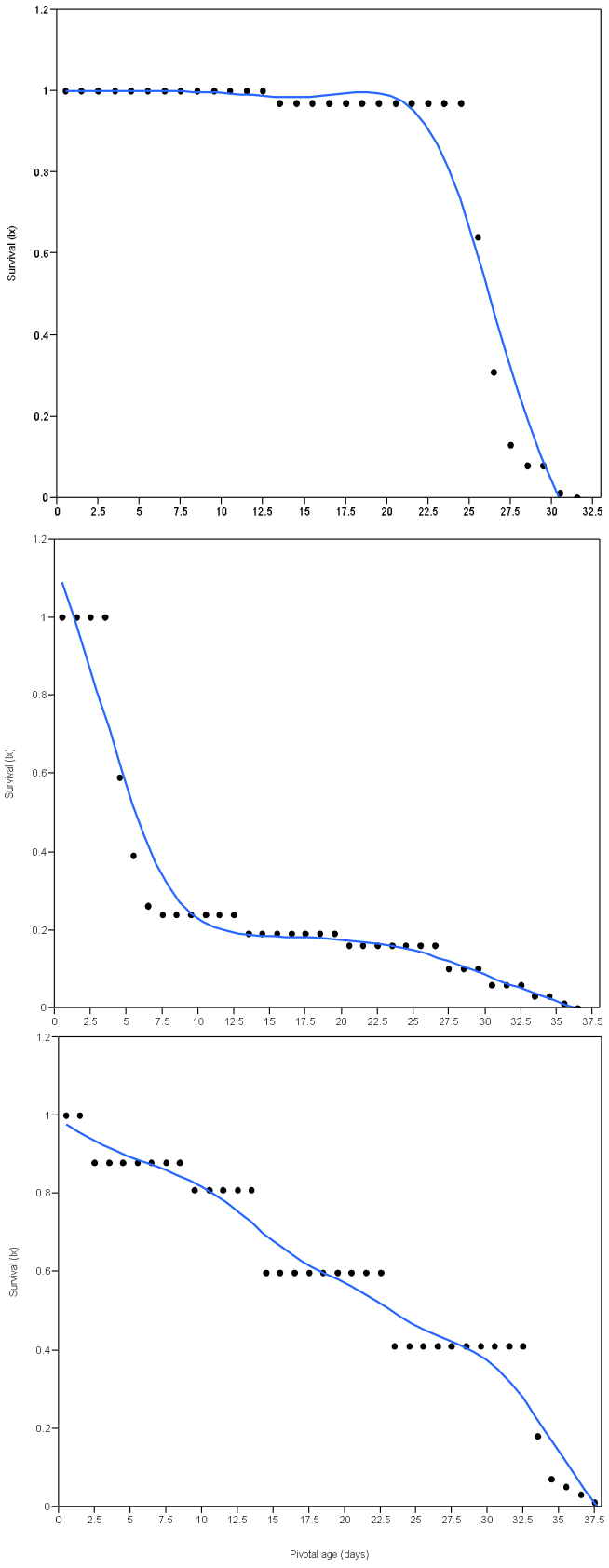

Figure 2. Age- specific survival (lx) of *P. solenopsis* at different phenophases of cotton during 2009.

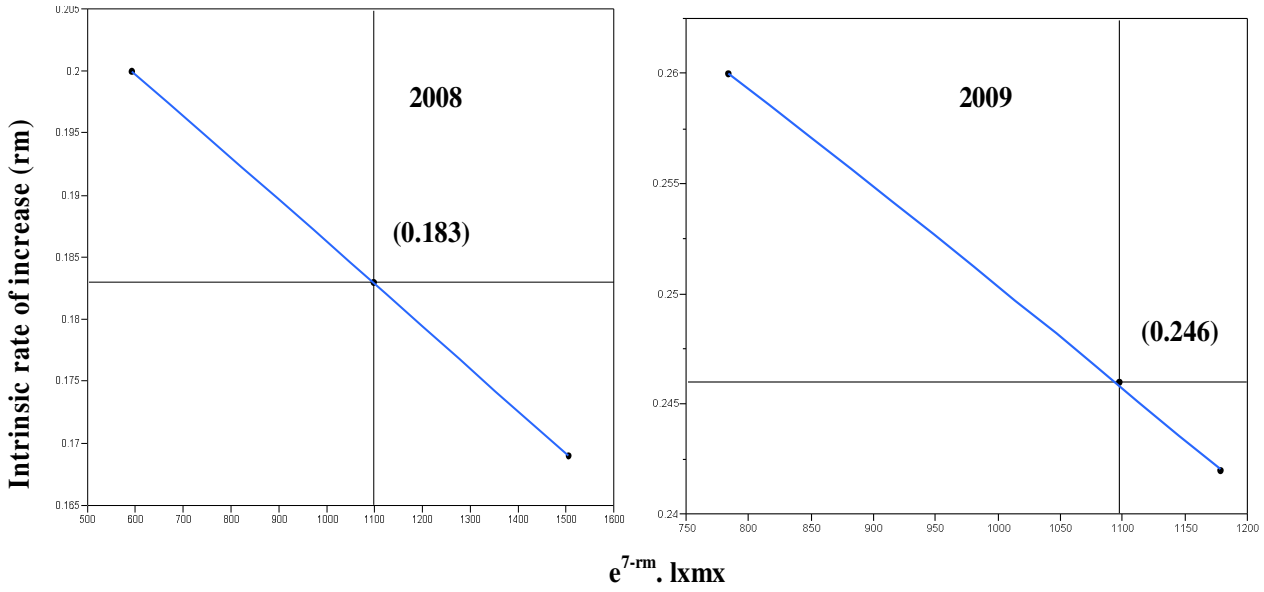

Figure 3. Precise value of r_m of *P. solenopsis* at vegetative stage on cotton under natural conditions.

Table 2. Life table of *P. solenopsis* at different phenophases under natural conditions in field during 2008.

Pivotal age in days (x)	Number of individuals in the beginning (l_x)	Number of individuals died (d_x)	Factors responsible for death (d_{xf})	Apparent mortality (100qx)	survival rate (s_x)
Vegetative stage					
Ist instar	300	-	-	-	1.00
2nd instar	300	223	Heavy rain fall	74.33	0.26
		4	*Aenasius* sp. and *Coccinella* sp, Rainfall in traces	5.19	0.94
3rd instar	73	8	Rain , high R H and *Aenasius* sp.	10.95	0.89
	65	6	*Aenasius* sp.	9.23	0.91
Adult stage		2	High RH	3.22	0.97
		57	Due to aging Life-cycle completed		
Flowering stage					
Ist instar	300	9	Probably > RH	3.00	0.97
2nd instar	291	225	Heavy Rain fall and *Coccinella* sp	77.31	0.23
3rd instar	66	47	Rain and *Aenasius* sp.	71.21	0.29
Adult	19	3	Probably R H >87%	15.79	0.84
	16	5	Rain	31.25	0.69
	11	11	Due to aging Life-cycle completed		
Maturation stage					
Ist instar	300	-	-	-	1.00
2nd instar	300	96	Probably > RH, Low temp and Heavy Rain fall	32.00	0.68
3rd instar	204	83	RH 90%, Low temp	40.69	0.59
Adult stage	121	37	Low temp	30.58	0.69
		84	Due to aging Life-cycle completed		

Table 3. Life table of *P. solenopsis* at different phenophases under natural conditions in field during 2009.

Pivotal age in days (X)	Number of individuals in the beginning (l_x)	Number of individuals died (d_x)	Factors responsible for death (d_{xf})	Apparent mortality (100qx)	Survival rate (s_x)
Vegetative stage					
1st and 2rd instar	300	-	-	-	1.00
3rd instar	300	97	*Aenasius* sp. and high rainfall	32.33	0.68
	203	155	Heavy rain	76.35	0.24
Adult stage		48	Due to aging		
			Life-cycle completed		
Flowering stage					
1st instar	300	124	Heavy rain fall	41.33	0.59
2nd instar	176	104	Rain and *Aenasius* sp. and *Coccinella* sp.	59.09	0.41
3rd instar	72	23	Rain	31.94	0.68
Adult stage	49	19	Rain	38.78	0.61
	30	13	*Aenasius* sp.	43.33	0.57
		17	Due to aging		
			Life-cycle completed		
Maturation stage					
1st instar	300	35	Rain fall	11.67	0.88
2nd instar	265	136	Probably > R H 85% and rainfall	51.32	0.49
3rd instar	129	6	Probably low temp	4.65	0.95
Adult stages	123	70	High rain fall	56.91	0.43
		53	due to aging		
			Life-cycle completed		

(90%) and low temperature. During 2009, no mortality in 1st and 2nd instar nymphs was observed when reared on vegetative stage (Table 3). The mortality in 3rd instar was due to Aenasius sp. and heavy rain fall (79.3 mm). At flowering stage, the apparent mortality in all the nymphal instars was due to the same biotic and abiotic factors as in vegetative stage. The main factors responsible for substantial mortality at maturation stage were rainfall (111 mm) and high relative humidity (>85%) in first and second instars, respectively. Mortality of third instar nymphs due to low temperature was negligible and 56.91% mortality observed at third instar and adult stage due to high rainfall and aging factors. The survival rate (Sx) was decreased with increase in the development stage during 2008 and 2009.

DISCUSSION

Results of this study indicated that different phenophases of cotton, as well as biotic and abiotic factors, had direct correlation with the life history of *P. solenopsis*. Previous studies on the table of mealy bugs were conducted under controlled and laboratory conditions; therefore, it is difficult to directly compare the results. Different scientists investigated the life table parameters of *Phenacoccus* species on different host plants. In this study, we found that the net reproductive rate was 65.29 and 278.46 at vegetative stage of cotton during 2008 and 2009. While the study conducted by Marohasy (1997) on age specific life tables of *Phenacoccus parvus* on seven plant species revealed that the net reproductive rate was maximum on lantana (263) followed by tomato (249) and eggplant (231), where as it was least in *Clerodendron*. However, the intrinsic rate of increase after adjustment was highest on eggplant while vegetative stage of cotton have maximum intrinsic rate of increase among the three phenophases studied in this research. In this study, heavy rain fall and high relative humidity are the major abiotic factors responsible for the mortality of *P. solenopsis* on cotton. Our study is in line with the findings of Suresh and Kavitha (2008) in which they concluded that high rainfall reduced the population of *P. solenopsis* on *Parthenium hysterophorus*. They further reported that for every unit increase in maximum temperature, evening relative humidity, rainfall caused significant population reduction (8.9, 0.46 and 0.96 units, respectively). Similarly, Akintola and Ande (2009) concluded that the mealy bugs are abundant on host plant during the dry season and more or less absent in rainy season. During the rainy season, crawlers were dislodging by the effect of rainfall and wind.

Survivorship and fertility of *Helopeltis antonii* measured under laboratory and field condition. The highest mortality occurred in the immature stages (first and second instar). The females lived for a maximum of 24 days. The intrinsic rate of increase (rm) was 0.092 per female per day and daily finite rate of increase (λ) was 1.097 females per female per day, with mean generation time of 27.70 days.

The net reproductive rate (R_o) of the population was 12.84 (Siswanto et al., 2001). Joshi et al. (2010) reported the bionomics, natural enemies and host range of *P. solenopsis* under controlled and laboratory conditions. The total life cycle completed in 16 to 38 days, whereas, in this study, 32.5, 37.0 and 39.5 days (approx.) at vegetative, flowering and maturation stage, respectively for both the seasons.

At the vegetative stage of cotton crop, the average temperature was varied between 23.7 to 40.3°C during 2008 to 2009. So this study is also compare with the studies conducted at control temperature too, although, R_o, T and λ were (65.29 and 278.46, 0.169 and 0.242, 1.184 and 1.274, respectively) at vegetative stage for 2008 and 2009 (in this study). However, in results on age specific cohort life table on *P. solenopsis* at 27 ± 2°C and 65 ± 5% RH (Fand et al., 2010) these were 123.41 females/female/generation, 28.34 days and 1.185 females/female/day, respectively. The mortality rate was high for the first instar crawlers, which declined sharply in subsequent instars. Study also revealed that R_o and T were higher than (15.51 females/female/generation and 34.23 days, respectively) reported in Persad and Khan (2002). The estimated intrinsic rate of increase (rm) at vegetative stage was 0.169 and 0.246 females/female/generation which was more than 1.4 to 2 times than those achieved at 25 and 27°C by *M. hirsutus* (Chong et al., 2008). This difference with the results of Chong et al. (2008) could be because of controlled conditions (at constant temperatures) and qualitative differences between cotton and hibiscus plant.

An understanding of the life table of *P. solenopsis* has important implications in management. Vegetative stage is most suitable for the production of its parasitoids and predators (e.g. *Aenasius* sp. and *Coccinella* sp.) to take advantage of high development rate, more fecundity and less mortality. A comparison between the life table parameters of *P. solenopsis* and its natural enemies, which not investigated in this study, is also helpful in selecting the most appropriate biological control agents especially these having high rm relative to this pest. Therefore, this study provides a pathway to the worker for comparing the life tale of natural enemies and *P. solenopsis*, to achieve efficient biological control. This study also provides farmer with information about the biotic and abiotic factor especially, rainfall and low temperature, which are detrimental for the growth of *P. solenopsis*. Such information used for the successful management of this pest under the Indian conditions.

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