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Life table parameters of papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink under laboratory conditions

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Abstract
Life table studies of papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink indicated that the net reproductive rate, representing the total female births (R_0) was 19.24 female per generation time (T_c) of 35.45 days on hibiscus leaves. The innate capacity of increase in number (r_c) was 0.083 and finite rate (λ) of increase was 1.094 females per female per day and a generation was completed in 32.967 days. The population was able to multiply 1.8737 times every week and the doubling time (DT) was 0.6337 days. The population on reaching a stable age distribution comprised approximately 98.31 per cent of immature stages of papaya mealybug.

Keywords: *Paracoccus marginatus*, life table, papaya

Introduction
Papaya mealybug (PMB), *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae) belong to native Mexico and Central America was introduced in the Caribbean island with gaining major pest status in vicinity in early 1990's; since 1994 and became spread in to South America in 1999, the Pacific Island in 2002 and South Asia in 2008. Papaya mealybug is an exotic pest recently invaded India (Muniappan *et al*., 2008) [5] and first reported in Pune vicinity of Maharashtra in July, 2010 (Nakat *et al*., 2012) [8]. Its extensive spread to neighbouring countries is also reported. Most recently papaya mealybug has expanded to Bangladesh, Combodia, Phillippines and Thailand reaching the Reunion Island by 2010 (Muniappan *et al.*, 2011) [6]. Life table studies are indicate fundamental to population ecology and gives most comprehensive description of the survivorship, development and a reproduction of a population (Price, 1997, Rickets and Miller, 1999) [9, 11].
As a newly invasive pest in Indian papaya ecosystem, particularly in Maharashtra state, there is meagre work reported on life fecundity tables. Therefore, life table parameters of PMB were investigated on papaya under laboratory conditions.

Materials and methods
The life fecundity tables were studies for papaya mealybug using hibiscus as host plant under laboratory conditions at Research Laboratory, Department of Agricultural Entomology, Post Graduate Institute, Rahuri during 2014-2015. Hundred eggs were kept on ten hibiscus leaf bits moist cotton in batches and observed their hatching at ambient temperature 27 ± 2 ^{0}C and 65 ± 5 % RH. Immediately after hatching, all the nymphs were reared individually on hibiscus leaves. Fresh food was supplied daily. The observations on nymph, pupae and adult development and their quiescent stages, successful adult emergence, fecundity and age specific mortality in different stages were made daily. For determining the specific fecundity, all the adults emerged on particular day were transferred on a separate hibiscus leaf for egg laying. The following column heading proposed by Birch (1948) [2] and further elaborated by (Atwal and Bains, 1974) [1] and (Nakat and Khaire, 1998) [7] were used to the construction of life fecundity table parameters of papaya mealybug. The number of individuals surviving at each age interval and also the mean number of females as well as offspring produced was recorded. The sum of the products of l_X, m_x (age relative survival of females x female births) was the net productive rate (R_0) which was the rate of multiplication of the population in each generation measured in terms of female produced per generation.
From the data, arbitrary values of $r_{m,}$ r_C and the mean: X - pivotal age in days; l_X - survival of mealybugs at age X; m_X - age schedule for mealybug births at age X. The values of X, l_X and m_X were calculated from the data on life-tables. The number of individuals survived at each age interval was recorded and also the mean number of mealybug offspring produced at each

age interval. The sum of the products l_X, m_x is the net productive rate (R_0). R_0 is the rate of multiplication of the females produced per generation. Number of times a population was calculated by the formula $R_0 = \Sigma\ l_X\ m_X$. From the data in life - table, the arbitrary values of r_m (r_C) and mean generation time (T) were calculated. The intrinsic rate of natural increase (r_m) of mealybug population was then calculated by using the life-table data from the value of arbitrary r_m by taking two trial values arbitrary selected on either side of it, differing in the second decimal place by interpolation method (Birch, 1948 and Wateson, 1964) [2]. Tables were then constructed with the column X and l_xm_x for each trial r_m. The two trial values of $\Sigma\ e^{7-\ rm\ X\ lx\ mx}$ were then plotted on the horizontal axis against their respective arbitrary r_m's on the vertical axis with the line drawn from the desired values of $\Sigma\ e^{7-\ rm\ X\ lx\ mx} = 1096.6$. The point of the intersection gave the value of true r_m accurate to the four decimal places. The stable age distribution was worked out by observing the population schedule of birth rate and death rate (m_X and l_X) and the age specific mortality of the immature as well as mature stages and the knowledge of r_m. The life expectancy table was constructed according to the method of Deevey (1947) [3] as summarized by Southwood (1968) [12] and Atwal and Bains (1974) [1].

Results

The data regarding the survival, fecundity and net reproduction rate in harmony with age of females of *P. marginatus* are presented in Table 1 and innate capacity of increase are presented in Table 2.

The results indicated that the maximum duration of egg, nymphs and adults was 11, 17 and 14 days, respectively. The average fecundity was recorded 355.15 eggs per female in 13 days of oviposition period. The average egg hatching per cent in PMB observed 86.00 per cent.

Age specific survival and fecundity rate of female

The data regarding the surviving and fecundity rate in accordance with the age of females of *P. marginatus* are presented in Table 1.

The maximum duration of egg and nymph was 11 and 17 days, respectively. The survival (l_x) from egg to adult (as friction of initial population of one) of *P. marginatus* recorded 0.86. The oviposition of the pest commenced on 28th day of pivotal age and continued upto 42nd day. The rate of production (m_x as female offspring) was found to increase steadily from 0.58 (12th day) to 13.55 (37th day). The substantial contribution was made by the female within first fifteen days of their life span. The mortality of females started from 29th day of pivotal age and continued upto 44th day when the last individual died.

Innate capacity for increase in number

It was seen from the Table 2 that, the mean generation time (R_0) of the *P. marginatus* was 19.24 days. The innate capacity (r_m) and finite rate (λ) for increase in numbers were calculated to be 0.083 and 1.094 females per female per day. At this rate, the population of *P. marginatus* was capable to multiply 1.8737 times per week under the set of condition. It took 0.6337 days to multiply the population in two folds. The hypothetical females were calculated as 370.30.

Stable age distribution

The stable age distribution of *P. marginatus* was worked out by observing the population schedule of birth rate and death rate (m_x and l_x) under the given set of conditions. It could be seen from the Table 3 that the eggs, I, II, III nymph and adult accounted for 75.42, 14.47, 5.53, 2.89 and 1.69. Thus, the major contribution (about 98.31 %) was made by immature stages as compared to adult stage (around 1.69 %) to the population of stable age of *P. marginatus*.

Life expectancy of the papaya mealybug

The life expectancy (e_x) of *P. marginatus*, determined at various age intervals (x) are presented in Table 4.

The perusal of the data revealed that the expected life of pest at the time of birth was 5.405 days. It decreased steadily in accordance with advancement of age and the expected life span of papaya mealybug on hibiscus was only 2.61 days at the age of 40th days.

Life table is a concise summary of certain vital statistics of insect population. It is a useful technique in the study of population dynamics which provides a format for recording and accounting of all population changes in the life cycle of a species. A life table generally describes the successive age intervals, the number of deaths, the remaining survivals and the rate of further life. The use of natural populations of insect pests has been discussed comprehensively by Birch (1948) [2] and Southwood (1968) [13].

Table 1: Life table for age specific survival, fecundity and net reproductive rate of *P. marginatus*

X	l_x	m_x	l_xm_x	l_xm_xX
1-11	1.0	Immature stages		
12	0.86	Pre-oviposition period		
13	0.86			
14	0.81			
15	0.76			
16	0.72			
17	0.67			
18	0.64			
19	0.62			
20	0.59			
21	0.58			
22	0.53			
23	0.49			
24	0.46			
25	0.42			
26	0.40			
27	0.38			
28	0.37	0.58	0.21	6.01
29	0.35	0.92	0.32	9.34
30	0.32	1.42	0.45	13.63
31	0.29	2.36	0.68	21.22
32	0.28	4.97	1.39	44.53
33	0.27	5.67	1.53	50.52
34	0.25	7.82	1.96	66.47
35	0.23	11.33	2.61	91.21
36	0.22	13.67	3.01	108.27
37	0.21	13.55	2.85	105.28
38	0.19	8.47	1.61	61.15
39	0.18	6.34	1.14	44.51
40	0.16	5.64	0.90	36.10
41	0.12	3.31	0.40	16.29
42	0.08	2.08	0.17	6.99
43	0.03	0.50	0.02	0.65
44	0.02	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00
			$R_0 = \Sigma\ l_xm_x = 19.24$	$\Sigma\ l_xm_x\ X = 682.15$

(R_0) = Net reproductive rate = 19.24

X = Pivotal age in days

l_x = Survival of female at different age intervals

m_x = Age schedule for female birth

Table 2: Calculations of life table studies

S. No.	Parameters	formula/calculations
1	Net reproductive rate (Ro)	$= \Sigma l_x m_x = 19.24$
2	Mean length of a generation TC	$= \frac{\Sigma l_x m_x X}{R_0} = \frac{682.15}{19.24} = 35.45$ days
3	Innate capacity for increase in numbers (r_c)	$= \frac{\text{Log } e^{(R_0)}}{T_C} = \frac{\text{Log } (2.9572)}{35.45} = 0.083$ Arbitrary r_c = 0.07, 0.08 and 0.09
4	Corrected r_m	$\Sigma e^{7\text{-rm}}$ X $l_x m_x$ = 0.0897 females/female/day
5	Corrected generation time (T)	$\frac{\text{Log } e^{(R0)}}{r_m} = 32.967$ days
6	Finite rate of increase in number (λ)	Antilog e (r_m) = 1.094 females/female/day
7	Weekly multiplication of population	$(er_m)^7 = 1.8737$
8	Doubling time (DT)	$\frac{\text{Log } e^{(2)}}{\text{Log } e^{(\lambda)}} = 0.6337$ days
9	Hypothetical F_2 females	$(R_0)^2 = 370.30$ females

Table 3: Stable age distribution of papaya mealybug, *P. marginatus* on hibiscus leaves

Pivotal age (X)	l_x	$e^{-rm\,x+1}$	$L_x\, e^{-rm\,x+1}$	% contribution in stable age	Stages
1	1.00	0.8358	0.8358	10.3572	
2	1.00	0.7641	0.7641	9.4686	
3	1.00	0.6985	0.6985	8.6562	
4	1.00	0.6386	0.6386	7.9136	
5	1.00	0.5838	0.5838	7.2346	
6	1.00	0.5337	0.5337	6.6139	Egg 75.42%
7	1.00	0.4879	0.4879	6.0465	
8	1.00	0.4461	0.4461	5.5277	
9	1.00	0.4078	0.4078	5.0535	
10	1.00	0.3728	0.3728	4.6199	
11	1.00	0.3408	0.3170	3.9279	
12	0.86	0.3116	0.2680	3.3206	
13	0.86	0.2848	0.2378	2.9475	
14	0.81	0.2604	0.2044	2.5333	I instar nymph 14.47%
15	0.76	0.2381	0.1762	2.1832	
16	0.72	0.2176	0.1513	1.8745	
17	0.67	0.1990	0.1303	1.6150	
18	0.64	0.1819	0.1146	1.4201	
19	0.62	0.1663	0.1006	1.2468	
20	0.59	0.1520	0.0889	1.1021	II instar nymph 5.53%
21	0.58	0.1390	0.0771	0.9559	
22	0.53	0.1271	0.0648	0.8030	
23	0.49	0.1162	0.0552	0.6837	
24	0.46	0.1062	0.0467	0.5790	
25	0.42	0.0971	0.0398	0.4933	III instar nymph 2.89%
26	0.4	0.0888	0.0346	0.4289	
27	0.38	0.0811	0.0304	0.3771	
28	0.37	0.0742	0.0267	0.3309	
29	0.35	0.0678	0.0227	0.2815	
30	0.32	0.0620	0.0189	0.2343	
31	0.29	0.0567	0.0162	0.2002	
32	0.28	0.0518	0.0142	0.1766	
33	0.27	0.0474	0.0123	0.1526	
34	0.25	0.0433	0.0104	0.1288	
35	0.23	0.0396	0.0089	0.1104	
36	0.22	0.0362	0.0078	0.0964	
37	0.21	0.0331	0.0066	0.0820	Adult 1.69%
38	0.19	0.0302	0.0056	0.0693	
39	0.18	0.0277	0.0047	0.0583	
40	0.16	0.0253	0.0035	0.0439	
41	0.12	0.0231	0.0023	0.0286	
42	0.08	0.0211	0.0012	0.0144	
43	0.03	0.0193	0.0005	0.0060	
44	0.02	0.0177	0.0002	0.0022	
45	0	0.0177	0.0000	0.0000	
			Σ8.0695	Σ100.00	Σ100.00

Table 4: Determination of life expectancy of *P. marginatus*

X	l_x	d_x	$100q_x$	L_x	T_x	e_x
0-5	100	0	0.00	100.00	540.50	5.405
6-10	100	24	24.00	100.00	440.5	4.405
11-15	76	17	22.37	74.00	340.50	4.60
16-20	59	17	28.82	58.50	240.50	4.11
21-25	42	10	23.81	41.00	166.50	4.06
26-30	32	9	28.13	30.50	108.00	3.54
31-35	23	7	30.44	22.50	67.00	2.98
36-40	16	16	100	14.00	36.50	2.61
41-45	0	0	0	0	14.00	0
46-50	0	0	0	0	0	0

X = pivotal age in days
L_x = Number of females alive in the age interval of age interval x
d_x = The number of dying during the age interval x

$100q_x$ = percentage mortality = $\left(\frac{d_x}{l_x} \times 100\right)$

L_x = alive between age x and X + 1 $\left(\frac{l_x + (l_x + 1)}{2}\right)$

T_x = The number of unit of time

e_x = expectations of further life $\frac{T_x}{l_x} \times 5$

Discussion

The oviposition of the pest commenced on 28th day. The rate of production (mx as female offspring) was found to increase steadily upto 37th day. Female made the substantial contribution within first nine days of their life span. The egg laying was observed upto 43rd day. The mean generation time (Tc) of *P. marginatus* was 35.45 days. The innate capacity (r_m) and finite rate (λ) for increase in numbers were calculated to be 0.083 and 1.094 females per female per day. At this rate population of papaya mealybug was capable to multiply 1.8737 times per week under the set of condition. It took 0.6337 days to multiply population in two folds. The hypotheitical females were calculated as 370.30. The results on stable age distribution of *P. marginatus* showed that major distribution was made by immature stage (98.31 %). The expected life of the pest was at the time of the birth was 5.405 days.

These present findings are in line with Khuhro *et al*. (2014) [4] on mango mealybug and Rahman Saljoqi *et al*. (2014) [10] on cotton mealybug.

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