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Study on Fecundity, Reproductive Rate, Intrinsic Rate of Increase and Effects of Diets on Adult Longevity, of a Long-tailed Mealybug, *Pseudococcus longispinus* (Targioni-Tozzetti) Parasitoid, *Leptomastix nr. epona* (Walker)

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Abstract: A life table was constructed for a new undescribed mealybug wasp, *Leptomastix nr. epona*, and effects of different feeding regimes were evaluated. Parasitoids with access to 50% honey solution had the longest life span and no significant differences were observed when fed on honeydew as well. Females lived significantly longer than males in all the treatments. Survival of male and female *L. nr. epona* fed on honey solution ranged from 10 to 39 and 29 to 61 days respectively. Potential fecundity of the two ages of parasitoid varied significantly with the size of parasitoid. Larger parasitoids had a higher number of eggs than the smaller ones. The gross reproductive rate (GRR), was 42.44 eggs/female/generation and net reproductive rate (R_o), was 28.02 females/female/generation. The intrinsic rate of increase (r_m), was 0.105 eggs/female/day. The mean generation was, 31.68 days and doubling time of the population was, 6.59 days. The mean fecundity reached a peak during the first 14 days and then started to decrease. The female proportion of the offspring produced in the life times of the parasitoid, *L. nr. epona* is half (0.54) of the total progeny and seems to be under the control of the female during her lifetime.

Key words: *Leptomastix nr. epona*, wasp, *Pseudococcus longispinus*, long-tailed mealybug, life table, intrinsic rate of increase

Introduction
Food is a component of the environment and may influence an animal's chance to survive and multiply by modifying its fecundity, longevity, or speed of development (Andrewwartha and Birch, 1954). The life span of adult parasitoids or their longevity may be regarded as an important factor in the overall quality of a parasitoid (Bigler *et al.*, 1987). The effect of host feeding on longevity varies among species (Heimpel and Collier, 1996). Parasitoids require food as adults and a lack of nutrient affects their life expectancy (Heimpel and Rosenheim, 1995). Nectar, pollen, homopteran honeydew, host blood or substitutes for these (e.g. diluted honey, cut resins, sucrose solutions) are important sources of parasitoid food (Jervis *et al.*, 1992). The effects of naturally occurring carbohydrates such as nectar, pollen, and honeydew on longevity and fecundity are known for some parasitoids. The provision of a range of diets for adult parasitoids has been shown to increase their longevity and fecundity (David *et al.*, 1987). Maternal diet is another factor that may affect a female's offspring sex ratio. Female *Bracon hebetor* feeding on hosts and honey produce significantly higher male offspring sex ratios than do females feeding only on hosts (Rotary and Gerling, 1973). This may be due to the increased longevity of females given honey in this species, older females produce exclusively sons when sperm is depleted (Rotary and Gerling, 1973). Briggs *et al.* (1995) reported that protein gained from host-feeding may also be used for maintenance and to prolong the life of the adult parasitoid. Three models of the evolution of host-feeding behaviour in parasitoid wasps are developed. The first assumes that the wasp host feeds purely to obtain resources to mature eggs (limited resource model) while the second assumes that host feeding provides energy for maintenance (pro-ovigenic model). The third model assumes that host feeding provides resources for both maintenance and egg maturation (resource model) (Chan and Godfray, 1993). The construction of life tables is an important component in the understanding of the population dynamics of a species (Southwood, 1978). Several criteria and diverse approaches exist for evaluating and selecting the best agents for controlling a pest (Waage, 1990). The age of the female parasitoids may influence their fecundity and sex ratio and knowledge of this sex ratio is important in their use in biological control programmes (Luck and Podoler, 1982; Waage, 1986). The effectiveness of a parasitoid species as a biological control agent is linked to the quality of an individual parasitoid's fitness (Ridgway

and Morrison, 1985). Fecundity is one of the biological parameters that can be used in assessing a parasitoid's fitness (Huettel, 1976) and is usually correlated to the size of the parasitoid (Charnov *et al.*, 1981; Waage and Ng, 1984; Opp and Luck, 1986; van den Assem *et al.*, 1989; LeMasurier, 1991; Rosenheim and Rosen, 1992). Parental age has been suggested to influence progeny production and sex ratio of parasitoids (Abdelrahman, 1974; van den Assem *et al.*, 1984; Cui *et al.*, 1986, King, 1987). The life table enables one to best visualize the relative contributions of survival and reproduction to the mean fitness of a population, so that the more comprehensive the life table, the more accurately can these contributions be described. Fecundity can be measured as potential or realized fecundity. The number of eggs present in the ovary at any one time is a useful conservative estimate of the potential fecundity for many species, particularly for pro-ovigenic insects. Female size, which may reflect the number of eggs present in the oviduct, can be used as a measure of potential reproductive output of many insects. However, the size of a parasitoid can most easily be estimated by either measuring the head width (van den Assem *et al.*, 1989; Liu, 1985) or the hind tibia length (Heinz and Parrella, 1989). As the synovigenic parasitoid emerges with fewer eggs than her full complement, dissection of ovaries at a certain age could only provide an estimate of egg-holding capacity of the parasitoid at that age and may not reflect actual or real fecundity of the parasitoid (Leather, 1988). Therefore, the present studies were carried out, I) to examine the effects of different kinds of adult diets such as honey solution and honey dew excreted by *P. longispinus* on the longevity of the parasitoid, ii) to investigate the influence of host feeding on the life span of the parasitoid which normally feeds on the body fluids of nymphal stages of mealybugs, iii) to examine the egg holding capacity of the parasitoids at a certain age as a measure of their potential fecundity at that age, iv) to find the relationship between the size (hind tibia length/ head width length between head to abdomen tip) and the potential fecundity of the parasitoids, v) to investigate the age dependent progeny production pattern of the parasitoid and vi) to calculate the intrinsic rate of population increase (r_m) of the parasitoids under laboratory conditions.

Materials and Methods
Effects of diets on adult longevity: Adult longevity of males and mated females of the parasitoid, *Leptomastix nr. epona* was

determined in the laboratory of Imperial College at Wye during the year 1998-2001, Wye, Ashford, Kent TN25 5AH, UK. Mummified *P. longispinus* containing pupae of the parasitoid was maintained in the incubator at 25± 1°C, 70-75% RH with continuous light. The individual mummies were kept in small vials (50 mm in length and 5 mm in diameter) at 25 ± 1°C, 70-75% RH in the incubator, until parasitoid emergence. Once the parasitoids had emerged, large sized males and females were selected (metathoracic tibia length or head-width was measured at the end of the experiment by dissecting under a microscope). Females were mated on the first day of emergence.

The five diets comprising distilled water (control treatment), 50% honey solution, host food, a combination of 50% honey solution and host food and honeydew of the mealybugs were provided to male and female parasitoids. The wasps were then placed individually in experimental patches consisting of a circular disc of *Passiflora coccinea* leaf (50 mm diameter) placed upside down in petri-dish containing a thin layer of agar gel to maintain high humidity. The Petri-dishes (50 mm diameter) with nylon mesh lids were then placed in large plastic boxes with 70-75% RH, which was maintained by using saturated solution of NaCl and were provided with each type of food as follows:

Drops of honey solution (50 %) and water were smeared on the screened lids. Two or three mealybugs of second instar were supplied daily on experimental patches by a fine camel hairbrush, as host food. Fresh honeydew was collected (on a piece of *Nerium* leaf) from the glasshouse where the *P. longispinus* were reared on *Nerium* plants (during each day several droplets of honeydew were deposited on a *Nerium* leaf). Fifteen replicate parasitoids were provisioned with each type of diet. Diets of all the treatments were replaced daily, until the death of the parasitoids, with freshly made honey solutions and new sets of hosts and honeydew. The parasitoids were placed in an incubator at 25± 1°C with 70-75% RH and continuous light intensity of 7W/m². The number of dead and living parasitoids was counted daily between 09:00 to 12:00 am until the death of all the individuals, when the longevity was calculated. Any individuals, which died accidentally by adhering to the sticky honey solution or which escaped from the petri-dish were excluded from the treatment analysis.

Life table study of the parasitoid: The parasitoid, *Leptomastix nr. epona* was cultured on the long-tailed mealybug, *P. longispinus* reared on butternut squashes. The mealybugs of the second instar, young adult and ovipositing adult were parasitized by the parasitoid species and kept in a CT room at 25 ± 1°C, 70-75% RH. for parasitoid emergence.

Potential fecundity: To study the relationship between the fecundity and parasitoid size, the mated parasitoids of different sizes were provided with honey and host-food (second instar) for 3 days and another set for 8 days and kept in an incubator at 25± 1°C, 70-75% RH and continuous light without hosts. They were then dissected in insect saline solution under a microscope to quantify the ovarian eggs. Holding the parasitoid in insect saline solution using a fine pin and then grasping and pulling the abdomen distally from the thorax performed the dissection. The ovaries became exposed and the clearly visible oocytes were counted, with mature eggs identified by the absence of nurse cells and by their size. As size may affect fecundity, parasitoids of similar body length (distance from head to tip of abdomen) (Van Dijken and Van Alphen, 1991) were chosen and also head width was used as a measure of body size of the wasps.

Age-specific fecundity: Adult females of the parasitoid, *Leptomastix nr. epona* obtained from laboratory cultures were used in this experiment.

Mummified *P. longispinus* containing pupae of the parasitoid was separated from butternut squashes/sprouted potatoes and kept individually in small glass vials (50 mm length and 10 mm in diameter) at 25± 1°C, 70-75% RH until the parasitoid emergence.

Leaf discs of *Passiflora coccinea* were placed with their lower surface facing upwards on the top of an agar gel layer in 6 cm diameter Petri-dishes. Female mealybugs of *Pseudococcus longispinus* of second instar (1.00≤2.00), young pre-ovipositing adult (2.00≤3.00 mm) and ovipositing adult (3.00≥3.00 mm) were used in this experiment. Twelve hosts within the limits of that size class were placed in each petridish. A freshly emerged female *Leptomastix nr. epona* which had mated once was used for the experiment. One female wasp per petridish was left to lay eggs on the twelve mealybugs of the size class mentioned for 24 hours. Thereafter, the wasp was transferred to another petridish with mealybugs of the same size class for oviposition, every 24 hours until her death. The petridishes with the female wasp were kept at 25± 1°C, 70-75% RH and continuous light and provided with 50 % honey solution on the lids of the as food. Each female wasp was considered as one replicate and nineteen replications were made. The number of mummies per day produced during the female wasp life, as well as the parasitoid survival and sex ratio of offspring were recorded. Hosts which were not mummified were dissected so that eggs which were encapsulated could be detected.

Life table parameters of the parasitoid: Life table parameters for the parasitoid were constructed using their survival rate and the number of female progeny per female per day. The sex ratio found in this study was used to calculate different life history parameters of the parasitoid.

The intrinsic rate of natural increase (r_m), which describes the growth potential of a population under a given set of environmental conditions (mean number of female offspring/female/day), gross reproductive rate (GRR), the number of eggs produced by females over their life time (mean number of eggs oviposited/female/generation), net reproductive rate (R_o), referring to the number of times a population will multiply per generation (mean number of female offspring/female/generation), cohort generation time (T_c), are approximations for the intrinsic rate of natural increase (r_m) and the generation time (T), respectively, generation time (T), doubling time (DT) which is the time required for a given population to double its number (days) and the finite capacity for increase (λ) that is the number of times the population will multiply itself per unit of time (mean number of female offspring/female/day) were calculated with the QBASIC program by Jervis and Copland (1996).

Analysis of the data: Data analyses were carried out on original data and on log-transformed data by using Analysis of variance in Genstat 5 release 4.1 version. The treatment means were compared by SED and also LSD at 5% level. Effect of parasitoid size on mean longevity of male and female on a particular food were compared using regression analysis in MINITAB. The relationship between potential fecundity and size of the parasitoids were analyzed using a simple regression and also paired t-test using MINITAB.

Results

Effects of diets on longevity of *L. nr. epona*: The effect of diet was highly significant on the longevity of male and female (F= 86.12 for diet; 68.64 for sex; 16.42 for diet and sex interaction on original data; df = 4; P< 0.01) (Table 1). Females with access to 50% honey solution had the longest life span and no significant differences were observed when fed on honeydew as well. Males with access to 50% honey solution and host food had the longest life span, which is significantly higher than the parasitoids fed on 50 % honey solution. Females lived significantly longer than the males in all treatments. Water fed male and female *L. nr. epona* lived 6.0 and 7.0 days respectively and host fed male and females lived 7.50 and 6.90 days respectively (Table 1).

Survival pattern of *Leptomastix nr. epona*: Feeding regime affected the adult longevity of *L. nr. epona*. Survival patterns of males and females of the parasitoid on different diets are
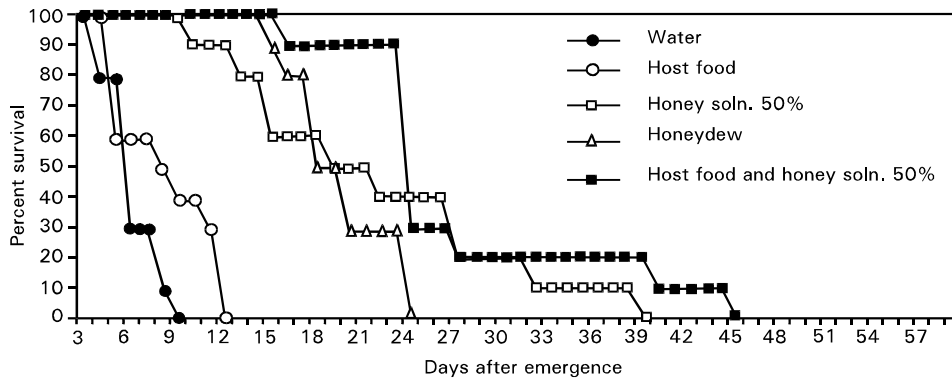
Fig. 1: Survival patterns of male *Leptomastix nr. epona* when fed on different dietary supplements, n = 10
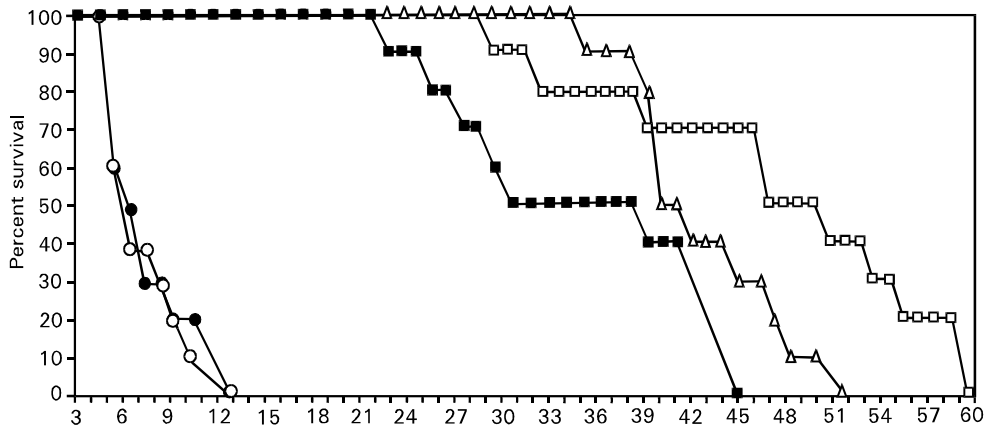

Fig. 2: Survival patterns of female *Leptomastix nr. epona* when fed on different dietary supplements. n = 10
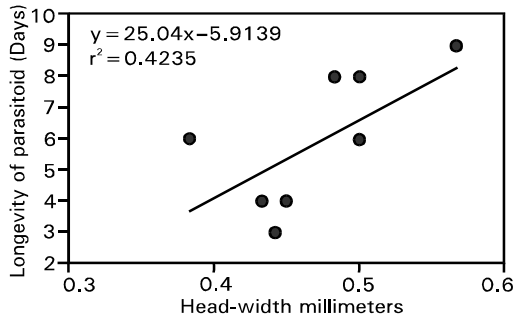

Fig. 3: Relationship of male parasitoid sizes (head-width) with longevity of parasitoid when fed on water
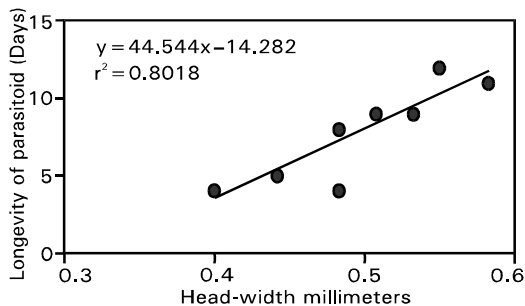

Fig. 4: Relationship of male parasitoid sizes (head-width) with longevity of parasitoid when fed on host food
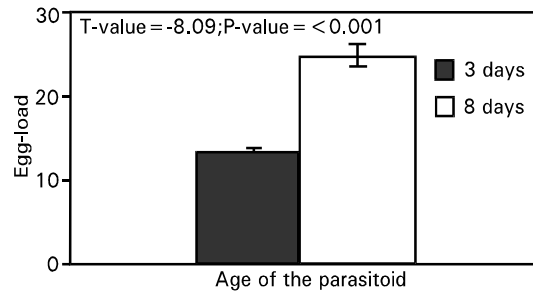

Fig. 5: Egg-load of two ages of parasitoid, *Leptomastix nr. epona* when fed with 50% honey solution and host-food. n= 13

presented in Fig. 1 and 2 respectively. Females of the parasitoid lived longer than males. A sharp decline of survivorship was observed on both sexes in the diet treatments of water and host food. Male of *L. nr. epona* lived longer when provided with host food and 50 % honey solution. Females of *L. nr. epona* lived longer when provided only 50 % honey solution. But female also lived longer when provided with honeydew of host mealybugs. Survival of male and females *L. nr. epona* fed on honey solution ranged from 10 to 39 days and 29 to 61 days respectively. Survival of female *L. nr. epona* fed on honeydew ranged from 35 to 50 days. From survivorship curves it appears that *Leptomastix nr. epona* follows Type II survivorship patterns (where there is a chance of death at any time).
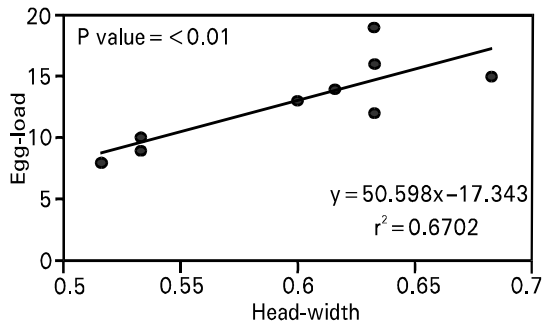
Fig. 6: Relationship between size (head-width) and egg-load in 3 days old parasitoid, *Leptomastix nr. epona* when fed with 50 % honey solution and host-food, n = 13
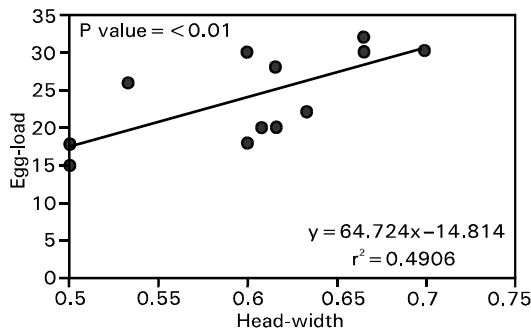

Fig. 7: Relationship between size (head-width) and egg-load in 8 days old parasitoid, *Leptomastix nr. epona* when fed with 50 % honey solution and host-food, n = 13
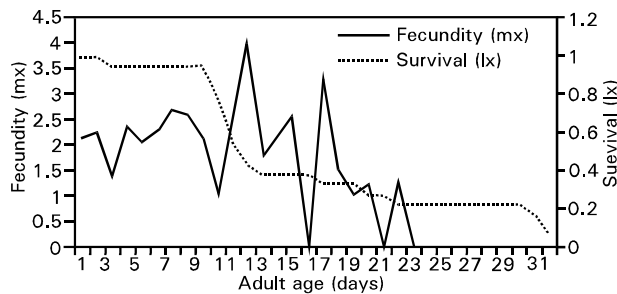

Fig. 8: Survival and female fecundity as measured on emergence of offspring

Relationship of longevity and size of the parasitoid when fed on different dietary supplements: There were no significant relationships between size and longevity of the parasitoid except in males only when fed on water and host food as a diet (Fig. 3 and 4).

Potential fecundity of the parasitoid, *Leptomastix nr. Epona*: Potential fecundity of the two ages of parasitoid varied significantly with the size of parasitoid. Larger parasitoids had a higher number of eggs than the smaller ones (Fig. 6 and 7). There was a positive linear relationship between the parasitoid size (head-width) and number of eggs in the ovary of 3 and 8 days old females of *Leptomastix nr. epona* (y = 50.598x - 17.343; r^2 = 0.6702; P< 0.01) and (y = 64.724x -14.814; r^2 = 0.4906; P< 0.01) respectively. Paired T-test showed that older parasitoid (8 days old) had higher eggs than younger ones (3 days old) (Fig. 5).
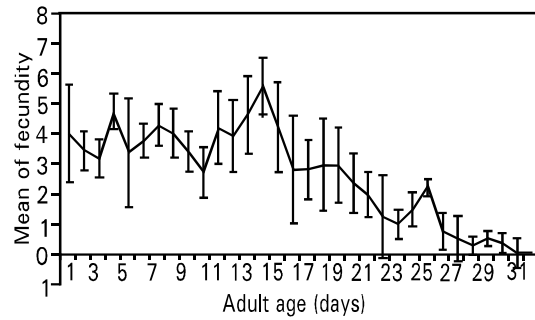

Fig. 9: Fecundity as measured by observing oviposition (male and female) of the solitary parasitoid, *Leptomastix nr. epona* on long-tailed mealybug, *Pseudococcus longispinus* at 25°C
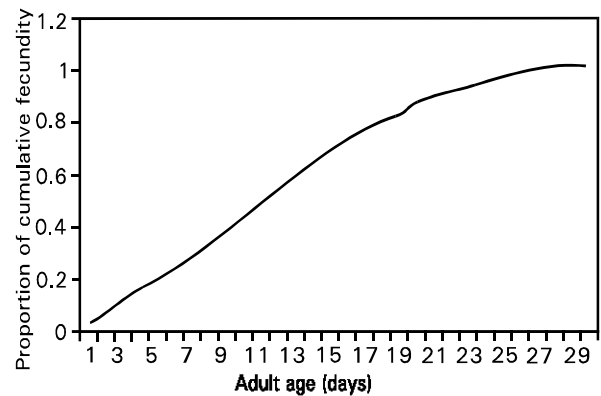

Fig. 10: Cumulative fecundity of *Leptomastix nr. epona* at 25°C and 70-75% r.h

Table 1: Effect of different diets on adult longevity (original data) of the parasitoid, *Leptomastix nr. epona* at 25°C, n= 10

Diets	Longevity of male ± SE	Longevity of female ± SE
Honey solution 50%	21.90 ± 2.93abB	45.10 ± 3.63aA
Water	6.00 ± 0.62cA	7.00 ± 0.80cA
Host food	7.50 ± 0.96cA	6.90 ± 0.77cA
Host food + honey solution 50%	25.90 ± 3.07aB	32.70 ± 2.64bA
Honeydew	19.30 ± 1.19bB	42.60 ± 1.57aA

P-value, for diets < 0.001; for sex = < 0.001 and for diet and sex interaction = < 0.001.
LSD- value at 5% level, for diet = 4.08; for sex = 2.58; and for diet and sex interaction = 5.77.
Means in rows followed by same uppercase letters are not significantly different at P= 0.05 (LSD).
Means in columns followed by same lowercase letters are not significantly different at P= 0.05 (LSD).

Table 2: Life table parameters of the parasitoid, *Leptomastix nr. epona* ovipositing in long-tailed mealybug, *Pseudococcus longispinus* at 25°C

Life table parameters	
Gross reproductive rate(GRR)	42.44 eggs/female/generation
Net reproductive rate (R_o)	28.02 females/female/generation
Capacity of increase (r_c)	0.10 female offspring/female/day
Intrinsic rate of increase (r_m)	0.11 eggs/female/day
Cohort generation time (T_c)	32.85 days
Generation time (T)	31.68 days
Finite capacity for increase (λ)	1.11 female offspring/female/day
Doubling time (DT)	6.59 days

Table 3: Mean number of eggs deposited by *L. nr. epona* with different survival times at 25°C

Parasitoid longevity ± SE	Replications	Mean eggs deposited
< 10 days (short survival)	5	110.2± 16.7a
10-20 days (medium survival)	6	38.33± 5.68a
> 20 days (long survival)	6	35.33± 6.38a
P value for treatment	0.004	

F value for treatment = 12.16; LSD value at 5% level = 90.08

Sex ratio: The secondary sex ratio of the parasitoid, *Leptomastix nr. epona* ovipositing in long-tailed mealybug, *Pseudococcus longispinus* during the life time of the female parasitoid at 25°C is shown in Table 4.

Life table parameters: The intrinsic rate of natural increase (r_m) and the associated life table parameters were determined (Table 2). Mean number of eggs deposited by parasitoids with different survival times varied (Table 3). The mean fecundity reached a peak during the first 14 days and then started to decrease (Fig. 8). The lowest fecundity was observed during last 15 days of the oviposition period of parasitoid (Fig. 9). Most of the eggs were laid during the first half of adult life. Only few eggs were laid daily in the later part of the oviposition period (Fig. 8-10).

Survivorship of adults remained high during the first nine days but after 10 days a sharp decrease in survival was observed; after 12 days the survivorship was around 40 % and for the last 9 days was around 20 % (Fig. 8).

Discussion

Influence of diets on parasitoid longevity: Adult parasitoids must not only find hosts for reproductive purposes but also locate food to meet their short-term nutritional needs (Lewis *et al.*, 1998). Many parasitoids must feed on carbohydrate rich non-host foods for survival and in the absence of hosts, parasitoids which are given carbohydrate-rich food, e.g. diluted honey solutions, live significantly longer than those given only water (Hagen, 1986; Jervis and Kidd, 1986; van Lenteren *et al.*, 1987; Kim and Morimoto, 1995).

Food consumption and utilization might be manipulated to improve the efficacy of natural enemies (Slansky, 1996). Many species of natural enemies cannot survive well in field crops, because of altered environmental factors or lack of nectar or pollen food sources for the adults. Laboratory studies have shown that in the absence of food, the parasitoid longevity of both sexes is in general significantly reduced (Jervis and Kidd, 1986).

Results of the present study provided useful information on survival of adult *Leptomastix nr. epona* on different diets. The provision of supplementary foods appeared to be an important means of promoting longevity of *Leptomastix nr. epona* and thus would reduce the frequency of augmentative release of the parasitoid in controlling *Pseudococcus longispinus*. Longevity of male and female *Leptomastix nr. epona* in the laboratory was found to be influenced by the feeding regime and was significantly higher with the presence of honey solution, honeydew, and honey solution plus host food.

Muegge and Lambdin (1989) suggested that diet is more

Table 4: The secondary sex ratio of the parasitoid, *Leptomastix nr. epona* ovipositing in long- tailed mealybug, *Pseudococcus longispinus* during the life time of the female parasitoid at 25°C

Maternal age in days	Living females	Ovipositing females	Total eggs laid	Total offsprings emerged	Female offsprings	Female proportion of the parasitoid offspring
1	19	19	79	26	15	0.58
2	19	16	68	16	10	0.60
3	18	16	60	22	9	0.41
4	18	17	88	25	12	0.48
5	18	16	63	17	10	0.59
6	18	16	70	10	7	0.70
7	18	14	79	18	11	0.61
8	18	16	74	16	10	0.63
9	18	13	63	18	11	0.61
10	15	9	42	11	4	0.36
11	10	10	43	9	5	0.56
12	8	7	32	7	7	1.00
13	7	5	33	8	3	0.38
14	7	7	40	13	5	0.39
15	7	6	30	10	6	0.60
16	7	5	20	1	0	0.00
17	6	4	20	1	1	1.00
18	6	4	18	2	1	0.50
19	6	5	18	3	1	0.33
20	5	5	12	4	2	0.50
21	5	2	10	0	0	0.00
22	4	3	5	1	0	1.00
23	4	2	4	0	0	0.00
24	4	4	6	0	0	0.00
25	4	4	9	0	0	0.00
26	4	1	3	0	0	0.00
27	4	2	2	0	0	0.00
28	4	1	1	0	0	0.00
29	4	2	2	0	0	0.00
30	3	1	1	0	0	0.00
31	1	1	0	0	0	0.00

Age at emergence = 23.08 days; Female proportion = 0.55; maternal age = is the age (days) of the ovipositing female; living females = is the survived female during the study and ovipositing female = is the female which lay eggs during study

important for survival of *Coccophagus lycimnia* (Walker) than temperature. *Encarsia formosa* Gahan is able to survive a prolonged period without hosts, in good conditions, when other food sources are present (van Lenteren *et al.*, 1987).

Females of the parasitoid lived longer than their male. Jahan (1997) also found similar findings when *M. helvolus* and *M. seyon* were fed with different feeding regimes. The phenomenon of females out living their males is also known to occur in several aphelinid parasitoids of *Coccus hesperidum* (Muegge and Lambdin, 1989).

From the survivorship curve it appears that *Leptomastix nr. epona* showed a Type II survivorship pattern (in which there is a constant risk of death) (Jervis and Copland, 1996). During these studies, the males did not fed on host food. Similar results were reported by Leius (1961) that males of *Scambus buolianae* (Hfg.) (Hymenoptera:Ichneumonidae) usually did not and probably cannot feed on body fluids.

During our longevity studies, females were not allowed to oviposit. The longevity of host-deprived females is longer than that of ovipositing ones (Table 3) where it was found that non-ovipositing females lived longer (45± 3.63 days) (mean ± SE) than ovipositing females (highest 32 days). Jahan (1997) found similar results when comparing the longevity of host-deprived females with those of ovipositing ones.

The present results indicate that *Leptomastix nr. epona* needs supplementary foods along with host-derived foods for their survival. When all diets were considered, honey and honeydew appeared to be better than the other diets. However, 50% honey and honeydew has a significant effect on the longevity of adult *L. nr. epona*. Therefore, the availability of sugar-rich food would improve the control of *Pseudococcus longispinus*. Lewis *et al.* (1998) and Stephen *et al.* (1997) reported that availability and accessibility of food sources, such as nectar or honeydew in a target area, strongly affect parasitoid retention and host-finding efficacy. For parasitoids to maintain high reproductive success it is important that disruption of their host foraging process is minimal so that most of their time and energy can be allocated to finding hosts.

Honeydew secreted by Homopteran hosts is a potential source of adult parasitoid food and could be used as a food source by many species (Idoine and Ferro, 1988; Cross and Moore, 1992). The honeydew of long-tailed mealybug had a positive effect on the longevity of the female parasitoid, *Leptomastix nr. epona*.

Feeding on honeydew may partly replace the feeding on host substances in order to obtain nitrogenous material (van Lenteren *et al.*, 1987). Jahan (1997) found a depressive effect of honeydew on the longevity of *M. helvolus* and *M. seyon*. The deleterious effects of some honeydews on the parasitoids' life span may be due to the presence of some complex chemicals (such as the sugar melezitose). Fischer and Shingleton (2001) mentioned that ant tended aphids honeydew had higher proportions of melezitose than untended aphids honeydew.

Knowledge of the nutritional ecology of adult parasitoids of mealybugs would help their mass rearing and utilization in a pest management programme. A diet of a complete mixture of proteins, vitamins and sugar, may further increase the quality of *Leptomastix nr. epona* in terms of increased longevity and fecundity and so improve control of *Pseudococcus longispinus*. Because, critical nutrients for the adult parasitoids are often scarce in large mono-crops areas, provisioning with plant derived food like nectars via the inter-planting of flowering herbaceous plants within the cropping system may improve biological control programmes using this parasitoid.

Fecundity and demographic statistics of the parasitoid: The success of the parasitoid depends upon relative competence to increase numbers and ability to find and attack the host (Waage and Hassell, 1982). The size of a parasitoid may be correlated with its fitness, so an understanding of the reproductive attributes and how individual parasitoids interact with their hosts is essential to evaluate the impact of a parasitoid species on its host (Doutt *et al.*, 1976).

The parasitoid, *Leptomastix nr. epona* laid more eggs over their life span (Table 3) than the number found at dissection at 3 and 8 days after eclosion (Fig. 5), which indicates that the parasitoid is synovigenic. Karamaouna (1999) reported that mean number of eggs in the ovaries of *L. epona* females emerged from different size hosts (*P. viburni*) were significantly different (Tukey, P≥0.05). The relationship between fecundity and the wasp size was evident in the parasitoid *Leptomastix nr. epona* in this study and the large size correlates with increased fecundity (Fig. 6 and 7). The positive linear relationship between the parasitoid size and potential fecundity of the parasitoid is in agreement with that of Karamaouna (1999). Being large may improve the female's ability to obtain hosts (van den Assem, 1971; King, 1987) and to produce more offspring (King, 1987; van den Assem *et al.*, 1989). Hence wasp size could be a good predictor of the number of ovarian eggs which itself is a very rough estimate of a parasitoid's potential fecundity (Tripathi and Singh, 1990) especially in the case of *L. epona* since it is synovigenic. Within a parasitoid wasp species the number and size of mature oocytes in the ovaries is positively correlated to some extent with the size of the parasitoid (Rosenheim and Rosen, 1992; Neill and Skinner, 1990). This observation has important implications for foraging models, since larger females may obtain larger fitness returns per host and also compared with smaller females, they can utilize a series of hosts in rapid succession (Neill and Skinner, 1990).

As the age influences the parasitoid's daily fecundity rate, the number of eggs a parasitoid individual can lay at a certain age is useful information to estimate the reproductive output of the parasitoid (Jahan, 1997). Depending upon the survival times the parasitoid (*Leptomastix nr. epona*) survival was divided into three different groups (i.e., short survival, medium survival and long survival, Table 3). The three different survival groups (short, medium and long) of *L. nr. epona* laid different mean numbers of eggs (110, 38 and 35 respectively). The female of the parasitoid, *L. nr. epona* showed a 3-phase pattern of age-dependent fecundity. Although there is a difference in the adult life span of the parasitoid, the life time fecundity schedule of the parasitoid with continuous exposure to hosts, showed that the fecundity plateau (the period of maximum egg-laying when females have produced ≥ 50 % of their total production capacity) occurred within 2 weeks of emergence (Table 4) so this information will be helpful for mass rearing the parasitoid as a biological control agent. Karamaouna (1999) reported that the mean fecundity of *Leptomastix epona* was dependent upon the size of host (large or small hosts) offered for oviposition. Old females of the parasitoid, *L. nr. epona* in a cohort seems to contribute a large number of female offsprings. Similar findings were found by Karamaouna (1999). Age specific survival (l_x) of the parasitoid, *L. nr. epona* remained high in the first nine days but after 10 days a sharp decrease in survival was observed. The female proportion of the offspring produced in the lifetime of the parasitoid *L. nr. epona* is half (0.55) of the total progeny. The secondary sex ratio of the offspring produced in the life time of the parasitoid *L. epona* appears to be of equal proportion of sexes in both large and small hosts of *P. viburni* (Karamaouna, 1999), which agrees with our findings.

The sex of the offspring (fertilization of the eggs) in *L. nr. epona* seems to be under the control of the female during its lifetime. Hence, secondary factors, like sperm depletion or viability and failures of the stimulation of the spermathecal gland owing to the age of females, do not seem to interfere with the selective fertilization by the parasitoid. Therefore, one mating of the female at the beginning of her life appears to supply it with sufficient sperm to fertilize the same proportion throughout its lifespan.

Estimation of the reproductive potential of parasitoids in the laboratory represents a maximum value, which may not be achieved in the field (Mishra and Singh, 1991). Therefore, for more realistic assessment of the performance and host utilization by the parasitoid *Lysiphlebus delhiensis*, the evaluation was restricted to the period of intensive egg laying as defined by Mackauer (1983). The intrinsic rate of natural increase (r_m) has been used as a bioclimatic index in parasitoid rating (Messenger, 1964). Therefore,

a high reproductive rate of the parasitoids is important so that the population of the natural enemy can rapidly increase when hosts are available. However, the predicted r_m (0.1052 female eggs/female/day) of *Leptomastix nr. epona* in the present laboratory studies may not reflect the actual effectiveness of the parasitoid in field conditions. In nature, numerous factors may modify this potential upward or downward, e.g. weather (moisture and temperature), photoperiod, natural enemies, inter and intraspecific competition and host plants and food quality over the plant growing seasons (Mehrnejad, 1998). *Leptomastix nr. epona* is a synovigenic species with a high gross reproductive rate (GRR) and short doubling time (DT). This may suggest that the parasitoid can be efficient to control long-tailed mealybugs. However, destructive host-feeding on small hosts *by L. nr. epona* increases parasitoid's efficiency to control younger hosts also. The life history parameters analysis clearly indicated that intrinsic rate of increase of the parasitoid did not alter after 2 weeks. These results suggest that the parasitoid *L. nr. epona* could be a good biocontrol agent for controlling *P. longispinus*. In a biological control programme, r_m can be used for the selection of a candidate parasitoid species in the absence of other criteria (Jervis and Copland, 1996), in our studies we found the r_m is low (0.1052 eggs/female/day) which is not a good indicator as a bio-control agent. But it may be used in association with other bio-control agent to control long-tailed mealybug, *Pseudococcus longispinus*.

Acknowledgments

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