Research Article

COMPARISON OF LIFE TABLE CHARACTERISTICS OF *MYZUS PERSICAE* (SULZER) (APHIDIDAE: HEMIPTERA) REARED FOR TWO SUCCESSIVE GENERATIONS ON CABBAGE (*BRASSICA OLERACEA* L. VAR. *CAPITATA*) UNDER AN AMBIENT CONDITION IN POKHARA, NEPAL

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ABSTRACT

The demographic characteristics of *Myzus persicae* (Sulzer) reared on cabbage (*Brassica oleracea* L. var. *capitata*) for two successive generations were studied for their comparative analysis by using the age-stage, two-sex life table. The studies were carried out in an ambient condition at premises of Agribusiness Promotion Support and Training Centre, Pokhara during November 2018 to February 2019. The intrinsic rate of increase (r), finite rate of increase (λ) and mean generation time (T) of *M. persicae* were 0.2751 d^{-1}, 1.3167 d^{-1}, and 15.2 d, respectively, for the first generation and 0.2571 d^{-1}, 1.2931 d^{-1}, and 16.6 d, respectively, for the second generation. The significant differences occurred in the intrinsic and finite rate of increase, and the mean generation time between two generations. These studies open new dimension to carry out similar experiment under laboratory and field situations to investigate effects of temperature, relative humidity and truly apply such findings for the benefit of commercial cabbage growers.

Key words: *Myzus persicae, aphid, life table, cabbage, intrinsic rate of increase.*

INTRODUCTION

The green peach aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae), the most destructive cosmopolitan pest causes considerable economic losses to various crops over 40 different plant families, including Brassicaceae. Its feeding can cause direct damage and may cause indirect damage through the transmission of over 100 plant pathogenic viruses (van Emden *et al*., 1969; Hughes, 1963; Ellis *et al*., 1998). In ecology, the age and stage structure, survival rate, developmental rate, and fecundity of a population are inclusively referred to as its “demography” or simply the “life table”. The life table is the oldest and one of the most important tools for analyzing and understanding the effect of external factors including host plants on the growth, survival, reproduction, and intrinsic rate of increase of

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insect populations (Chi and Su, 2006). Based on the life table, population projections can be performed using computer simulation (Chi, 1990). Life tables have been used in diverse types of studies related to population ecology, such as the population biology of invasive species (Sakai *et al*., 2001), conservation strategies (Wilcox and Murphy, 1985), demographic eco-toxicology (Stark and Banks, 2003), harvesting theory (Chi and Getz, 1988; Chi, 1994), and pest control timing (Chi, 1990).

Numerous life table studies of *M. persicae* have been performed under varying conditions, including different temperatures (Huiyan *et al*., 1995; Zhou *et al*., 2014), different host plants and cultivars (Davis *et al*., 2007; Kaydan *et al*., 2006; Özgökçe *et al*., 2018; Rossa *et al*., 2013) and exposure to insecticides (Zeng *et al*., 2016; Tang *et al*., 2015; Tang *et al*., 2019). Many of these studies are based on an age-specific female life table that ignores the overlap of developmental stages in *M. persicae* populations or calculates age-specific fecundity based on the "adult age" or used approximation techniques for estimation of the intrinsic rate of increase. Such methods and techniques of studying life table create various shortfalls and leads to an erroneous relationship among gross reproductive rate, net reproductive rate, and pre-adult survivorship (Huang and Chi, 2012; Yu *et al*., 2005). Chi and Liu (1985) and Chi (1988) developed an age-stage two-sex life table theory which properly addresses the shortcoming of traditional forms of life tables. Age-stage two-sex life table theory has been applied to insect pests (Gabre *et al*., 2005; Silva *et al*., 2006; Yin *et al*., 2009; Yin *et al*., 2010; Bailey *et al*., 2010, Jha *et al*. 2012 a,b, 2014; Huang and Chi, 2012), mites (Kavousi, 2009), predator life table and predation rate studies (Chi and Yang, 2003; Yu *et al*., 2005; Mo and Liu, 2006), life tables of parasitoids and parasitism rate (Masood and Chi, 2006; Chi and Su, 2006), temperature-dependent demography (Yang and Chi, 2006; Tsai and Chi, 2007) and eco-toxicological studies (Schneider *et al*., 2009).

The growth and development of insects vary among their successive generations and are affected by various abiotic factors including their host plants, and necessities to construct life tables under different conditions for an ecologically based pest management program for *M. persicae*. For all of these, it is crucial to choose the age-stage, two-sex life table to obtain comprehensive, precise and meaningful analytical results. In this study, demographic characteristics of *M. persicae* reared on cabbage was compared for two successive generations under an ambient condition by using the age-stage, two-sex life table approach, which is useful in developing IPM strategies against *M. persicae*.

MATERIALS AND METHODS

Host plant: Cabbage (*Brassica oleracea* L. var. *capitata*) was selected as it is one of the most preferred hosts of *M. persicae* and being one of the most popular vegetable in the world. It is also an important commercial vegetable grown in Nepal since longtime. Cabbage seedlings were grown in net house to prevent aphid infestation in batch at 15 to 20 days interval to maintain tender leaves for insect rearing. Such seedlings were grown in 24-well-plastic tray and coco pit-compost nursery mix in 3:1 ratio.

Test insect: The colony of *M. persicae* was established inside net cage in the premises of Agribusiness Promotion Support and Training Centre (ABPSTC), Pokhara with apterous adults collected from pesticide non-contaminated cabbage field, Pokhara sub-metropolitan city, Gandaki Province, Nepal. The colony was periodically supplemented with nymphs collected from pesticide non-contaminated field to maintain its genetic heterogeneity.

Life table study: Before the life table study, 25 adults from stock colony were reared on cabbage for one generation at indoor ambient condition. Daily mean temperature and relative humidity of experiment room (indoor) and field (outdoor) during whole experiment period is given in Fig 1. Nymphs from each female were collected in plastic cups (0.5 liter capacity with diameter of 10 cm base, 11.5 cm top and 6.5 cm height) and kept separately at ambient condition. A total of 50 nymphs (1 to 2 nymphs from each female) were used for the life table studies. The nymphs born within 24 hrs. were individually transferred to leaves placed in similar plastic cups by using a fine camel hair brush. The individuals were observed daily for molting and survival till adult stage. The leaves were replaced in every alternate day. Each day, adults were checked for reproduction and nymphs were counted. Survival and fecundity were recorded for each individual until death.

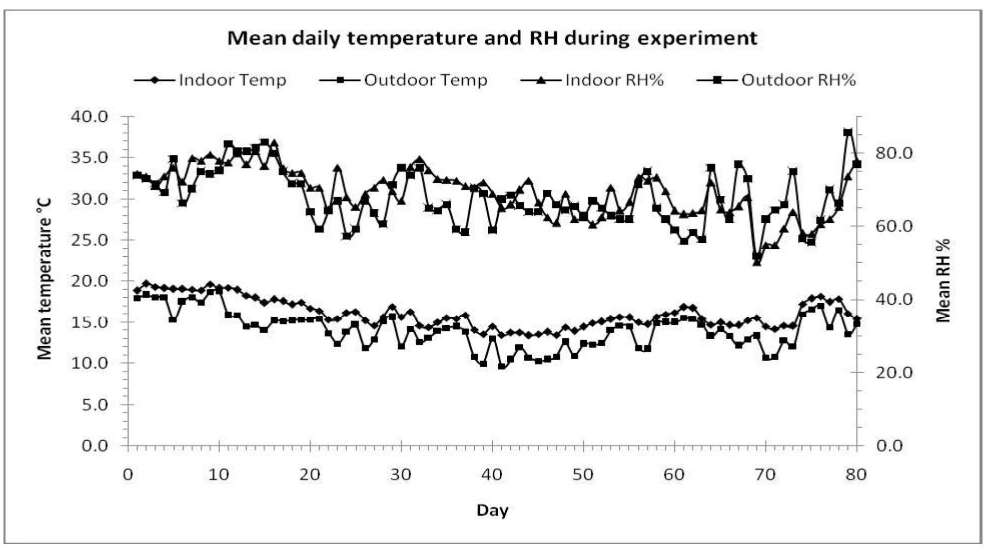


Fig. 1: Indoor and outdoor temperature (*°C*) and relative humidity (RH%) during 21 November 2018 to 8 February 2019 at ABPSTC, Pokhara

Data analysis: Raw data were analyzed based on the theory of the age-stage, two-sex life table (Chi and Liu, 1985; Chi, 1988). The mean of the development periods for each development stage, longevity for all individuals and females, total pre-reproduction period

(TPRP) and female fecundity of *M. persicae* were calculated. The TPRP was calculated by including the pre-adult age in the total. The age-stage specific survival rate (s_{xj}) (where x is the age and j is the stage), the age-stage specific fecundity (f_{xj}), the age-specific survival rate (l_x), and the age-specific fecundity (m_x) were calculated from the daily records of the survival and fecundity of all individuals in the cohort.

The intrinsic rate of increase was estimated by using the iterative bisection method from the Euler-Lotka formula with age indexed from 0 (Goodman, 1982):

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1 \quad (1)$$

The bisection method can be found in most textbooks of numerical analysis (Burden and Faires, 2005). The finite rate λ is calculated as e^r. The net reproductive rate is the total offspring that an individual can produce during its life time and is calculated as:

$$R_0 = \sum_{x=0}^{\infty} l_x m_x \quad (2)$$

The mean generation time (T) is defined as the time that a population needs to increase by a factor of R_0 as the stable age-stage distribution and the stable increase rate (i.e. r and λ) are reached. The relationship defining T is $e^{rT} = R_0$ or $\lambda^T = R_0$, and the mean generation time is then calculated as $T = \ln R_0 / r$. The gross reproductive rate (GRR) was calculated as $GRR = \sum m_x$. Based on the age-stage, two-sex life table, the life expectancy for individual of age x and stage y (e_{xy}) was calculated as:

$$e_{xy} = \sum_{i=x}^{n} \sum_{j=y}^{m} s'_{ij} \quad (3)$$

Where, n is the last age of the cohort, m is the number of stages, and s'_{ij} is the probability that an individual of age x and stage y will survive to age i and stage j and is calculated by assuming $s'_{xy} = 1$ and following the procedures described by Chi (1988) and Chi and Su (2006).An analysis of the raw data and an estimation of the life table parameters including the age-stage specific life expectancy (e_{xj}), the age-stage specific reproductive value (v_{xj}) were performed using a user-friendly computer program, TWOSEX-MSChart (Chi, 2020) available at http://140. 120.197.173/Ecology/Download/Twosex-MSChart.zip. The standard errors of the life table parameters were estimated by using the bootstrap technique with 100,000 re-samplings included in the TWOSEX-MSChart. The bootstrap paired test were carried out in TWOSEX-MSChart to evaluate the differences in development times, fecundities and the population parameters of *M. persicae* reared between two successive generation.

RESULTS AND DISCUSSION

Mean temperature and relative humidity of experiment room (indoor) and field (Outdoor) are given in Table 1. The indoor mean temperature and relative humidity were significantly higher than the outdoor condition.

Table 1. Mean temperature and relative humidity during two successive generation of *M. persicae* at ABPSTC, Pokhara

Experiment	**Statistics**	**Temperature (°C)**		**Relative Humidity (RH %)**	
		Indoor	**Outdoor**	**Indoor**	**Outdoor**
First Generation	*n*	372	372	186	186
	Mean ± SE	16.1 ± 0.1	14.2 ± 0.2	70.0 ± 0.6	67.3 ± 1.0
Second Generation	*n*	348	348	174	174
	Mean ± SE	15.7 ± 0.1	13.7 ± 0.2	68.3 ± 0.5	66.4 ± 0.7

n = number of observations

The development periods for each stage, adult longevity, pre-reproduction period, and female fecundity of *M. persicae* reared on cabbage for two successive generations are given in Table 2.

Table 2. Basic statistics of the life history of *M. persicae* reared on cabbage for two successive generations at ABPSTC, Pokhara

Statistics	Stage or Sex	Generation				*P*
		First		Second		
		n	Mean ± S.E.	*n*	Mean ± S.E.	
Preadult duration(d)	N_1	50	2.00 ± 0.13	50	1.80 ± 0.06	0.1600
	N_2	49	2.47 ± 0.12	50	2.14 ± 0.09	0.0258*
	N_3	49	2.02 ± 0.11	50	2.64 ± 0.15	0.0008**
	N_{4-5}	49	2.24 ± 0.14	49	3.16 ± 0.15	0.0000**
Adult longevity(d)	Female	49	35.76 ± 2.5	49	40.22 ± 2.24	0.1783
Longevity (d)	All	50	43.70 ± 2.5	50	49.16 ± 2.3	0.1121
TPRP (d)	Female	49	8.98± 0.19	49	9.73±0.13	0.0012**
Fecundity(*F*) (offsprings/female)	Female	49	67.3± 3.36	49	73.71± 2.46	0.1244
Oviposition period (d)	Female	49	22.04 ± 1.2	49	23.92 ± 0.96	0.2247

TPRP (Total pre-reproduction period) ; All *P* values are calculated at P < 0.05 by using paired bootstrap test implemented in TWOSEX-MSChart. Standard errors (SE) were estimated by using the bootstrap technique with 100,000 re-samplings

Significant differences in nymphal duration of third instar (P≤0.001) and fourth and fifth instar (P≤0.001) were found between two generations of *M. persicae*. Most individuals had four nymphal stages, whereas a few had five nymphal stages. Longevity of cohort in the first generation and the second generation was 43.7 days and 49.1 days, respectively.

The mean total pre-reproduction period (TPRP) of the first and the second generation of *M. persicae* was 8.98 days and 9.73 days, respectively. This difference was statistically significant (P≤0.001). The mean fecundity of *M. persicae* in the first and second generation was 67.3 and 73.7 offspring per female, respectively. There was no significant difference in longevity of cohort and the mean fecundity (Table 2).

The curves of age-stage survival rate (s_{xj}) show the probability that an individual of *M. persicae* surviving to age x and stage j (Fig. 2). The overlap among the stage-specific survivorship curves is the result of the variation among individuals in the rate of development. The l_x curve is the age-specific survival rate including all individuals of the cohort (Fig. 2) and ignoring the stage differentiation. It is thus a simplified version of the s_{xj} curves. The female age-specific fecundity (f_{x6}) shows the mean number of offspring produced by the female adult (the sixth stage) at age x (Fig. 3). If all individuals of age x are included, this value expresses the age-specific fecundity of the total population (m_x). The product of l_x and m_x is the age-specific maternity ($l_x m_x$) of *M. persicae*. Higher peaks of f_{x6}, m_x, and $l_x m_x$ were observed in the second experimental generation of *M. persicae*.

Table 3. Mean ± S.E. of population parameters of *M. persicae* reared on cabbage for two successive generations at ABPSTC, Pokhara

Population Parameters	Generation				*P*
	First		Second		
	n	Mean ± S.E.	*n*	Mean ± S.E.	
r	50	0.2751 ± 0.0064	50	0.2571 ± 0.0033	0.0129*
λ	50	1.3167 ± 0.0085	50	1.2931 ±0.0042	0.0132*
R_0	50	66.0 ± 3.5	50	72.2 ± 2.8	0.1675
T	50	15.2 ± 0.32	50	16.6 ± 0.21	0.0002**
GRR)	50	79.2 ± 1.5	50	80.4 ± 1.2	0.5573

r, intrinsic rate of increase (d^{-1}); *λ*, finite rate of increase (d^{-1}); R_0, net reproductive rate (offspring/individual); T, mean generation time (d); *GRR*, Gross reproduction rate (offspring/ individual).

Standard errors (SE) were estimated by using the bootstrap technique with 100,000 re-samplings.

All *P* values are calculated at P < 0.05 by using paired bootstrap test implemented in TWOSEX-MS Chart

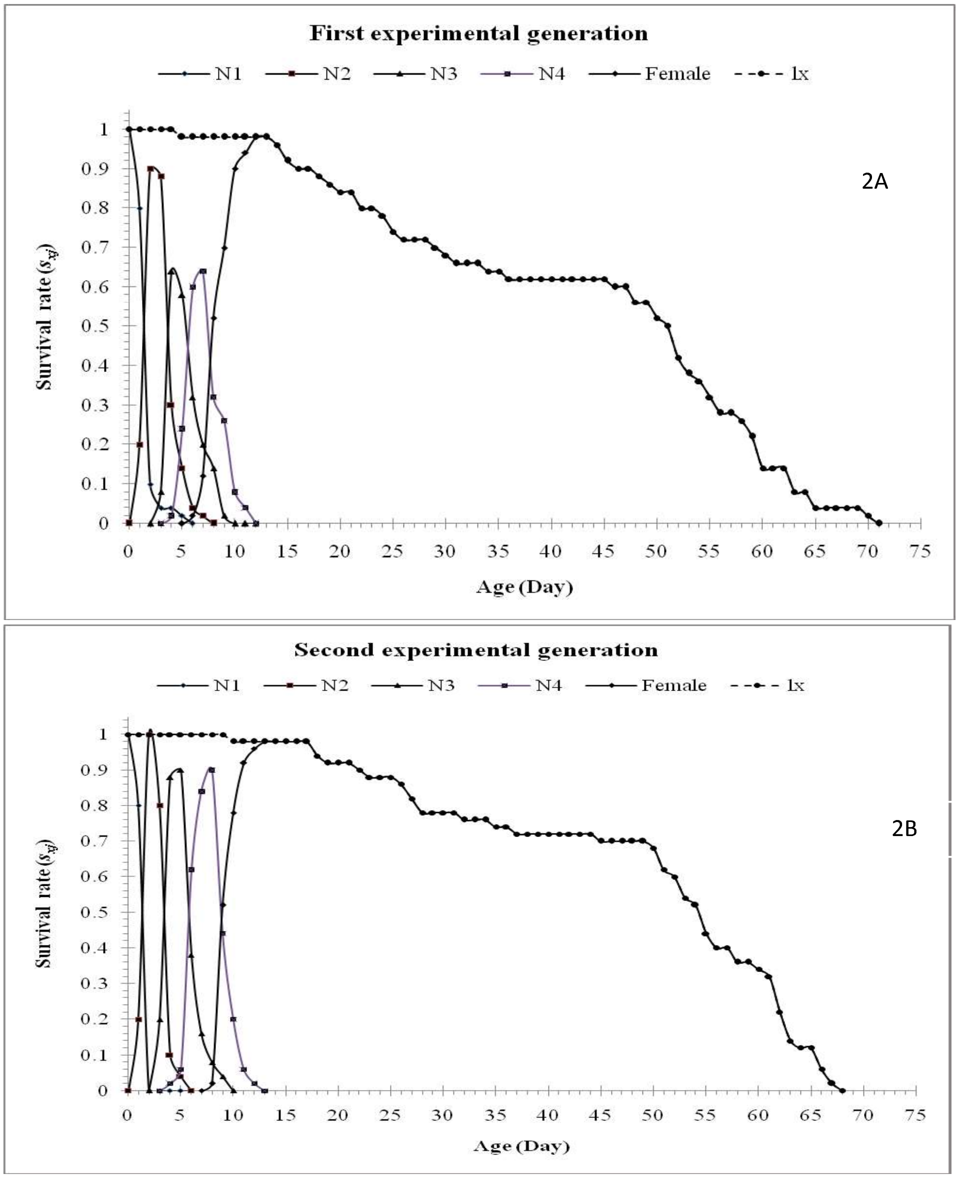


Fig. 2: Age-stage specific survival rate (s_{xj}) and Age-specific survival rate (l_x) of *M. persicae* reared on cabbage for two successive generations at ABPSTC, Pokhara. 2A- First experimental generation; 2B-Second experimental generation.

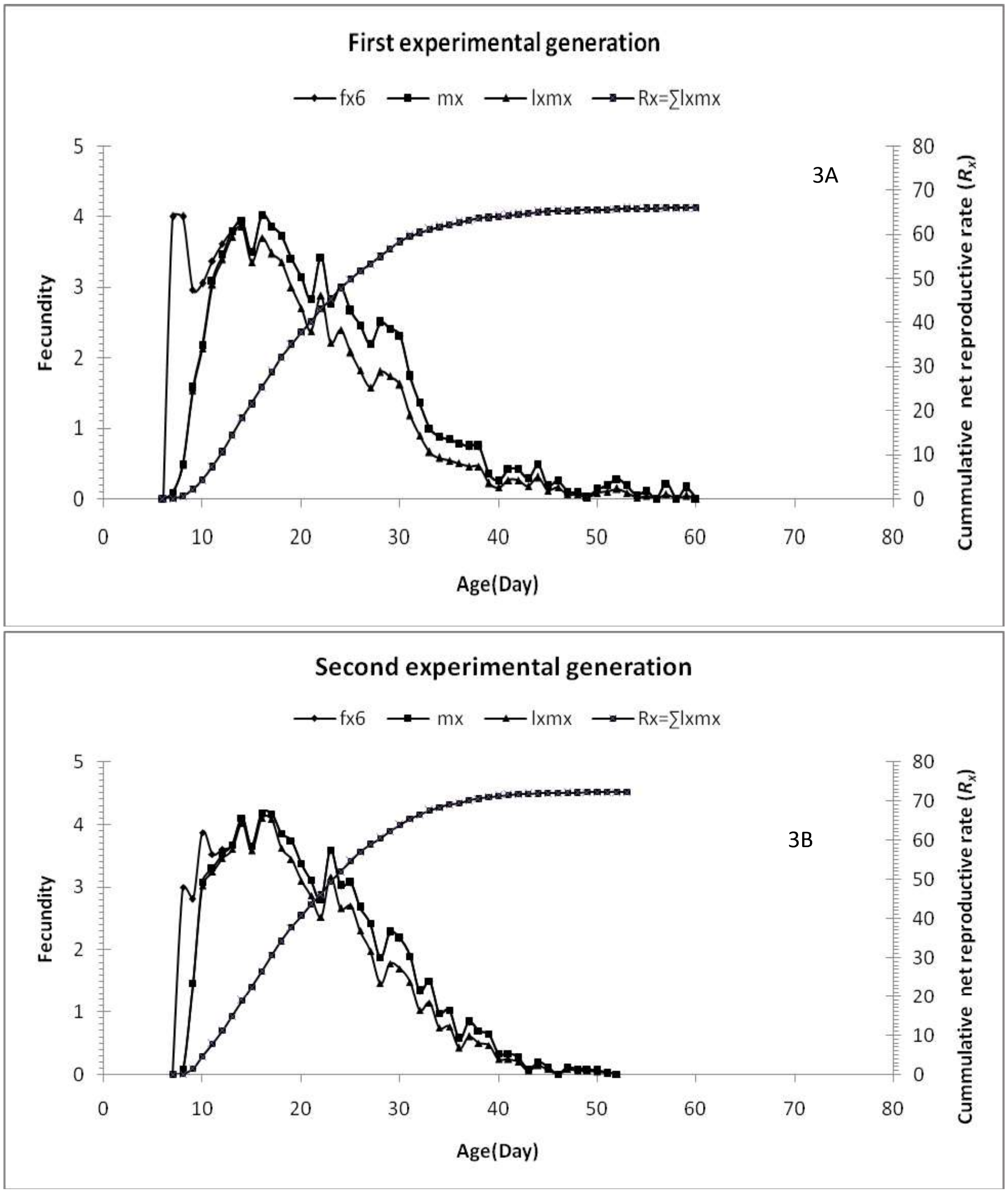


Fig. 3: Female age-specific fecundity (f_{x6}), age-specific fecundity (m_x), age-specific maternity (l_xm_x) and cumulative net reproductive rate (R_x) of *M. persicae* reared on cabbage for two successive generations at ABPSTC, Pokhara. 3A- First experimental generation; 3B-Second experimental generation

The age-stage life expectancy (e_{xj}) shows the total time that an individual of age x and stage j is expected to live (Fig. 4).The age-stage life expectancy of the cohort of *M. persicae* in the second generation was shorter than in first generation. The reproductive value (v_{xj}) (Fig. 5) is defined as the contribution of an individual of age x and stage j to the future population (Fisher, 1930).

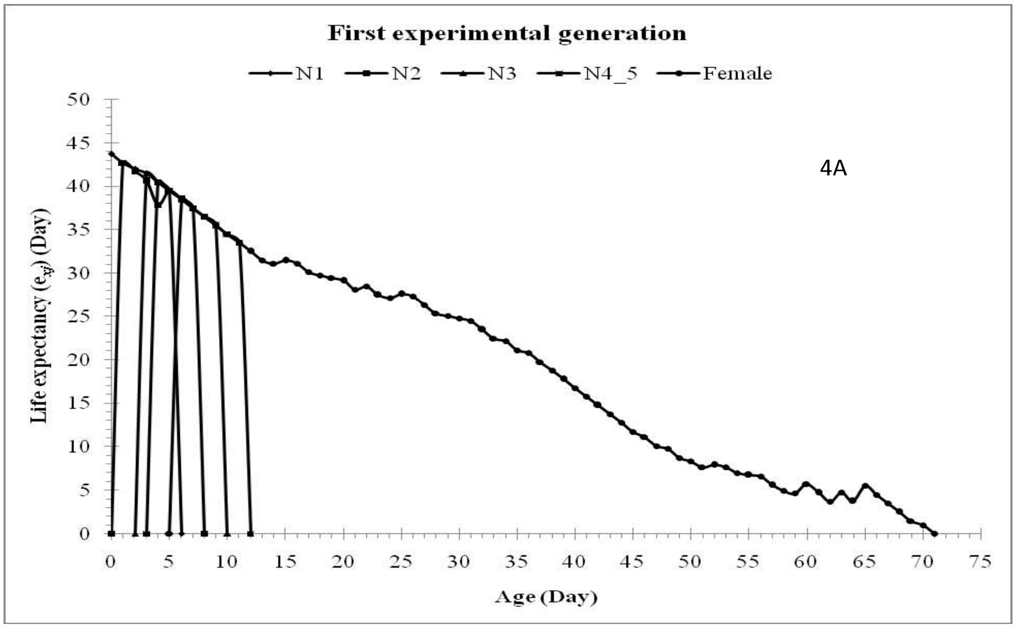
The means and standard errors of r, λ, R_0, GRR, and T are given in Table 3. The intrinsic rate of increase (r) and the finite rate of increase (λ) for *M. persicae* were 0.2751 d^{-1} and 1.3167 d^{-1}, respectively, in the first generation, which are significantly higher than those in the second generation (r = 0.2571d^{-1}, λ = 1.2931 d^{-1}). In first generation, R_0, T and GRR for *M. persicae* were 66.0 offspring, 15.2 d, and 79.2 offspring, respectively. In the second generation, R_0, T and GRR were 72.2 offspring, 16.6 d, and 80.4 offspring, respectively. No differences were found in R_0 or in GRR for *M. persicae* between two successive generations. However, significant differences were found in r, λ and T. These results are consistent with the findings of Tang *et al.* (2019), who studied life table of *M. persicae* for two generations by rearing on Chinese cabbage leaf discs at 23 ±1˚C, 65–75% RH, and a photoperiod of 16: 8 (L:D) hrs.

The results of this study fully illustrate the concept of the age-stage, two-sex life table. The study also demonstrates the advantages of the age-stage, two-sex life table over the traditional age-specific life table for describing demography (Lewis, 1942; Leslie, 1945; Birch, 1948; Caswell, 1989; Carey, 1993). For example, the overlap in the developmental stages of *M. persicae* resulting from the variation among individuals in developmental rates is represented by the overlapping s_{xj} curves in Figure 2. These results show the potential of the age-stage, two-sex life table for revealing the actual scenario of stage differentiation of *M. persicae*. Similar overlapping can also be observed in the e_{xj} and v_{xj} curves (Fig. 4 and 5).

As shown by Chi (1988), for a two-sex population, the correct relationship between the net reproductive rate (R_0) and the mean female fecundity (F) is:

$$R_0 = F \cdot \left(\frac{N_f}{N} \right) \quad (4)$$

Where, N is the total number of individuals used for life table study and N_f is the number of female adults emerged from N. In this study, the cohort sizes (N) are 50 for life table study of both generations where 49 individuals emerged females (N_f). R_0 and F data of both of studies are consistent with the relationship of Equation 4. Our results are also consistent with the relationship between R_0 and GRR: $R_0 < l_a \cdot GRR < GRR$ (Yu *et al.*, 2005), where l_a is the pre-adult survivorship.



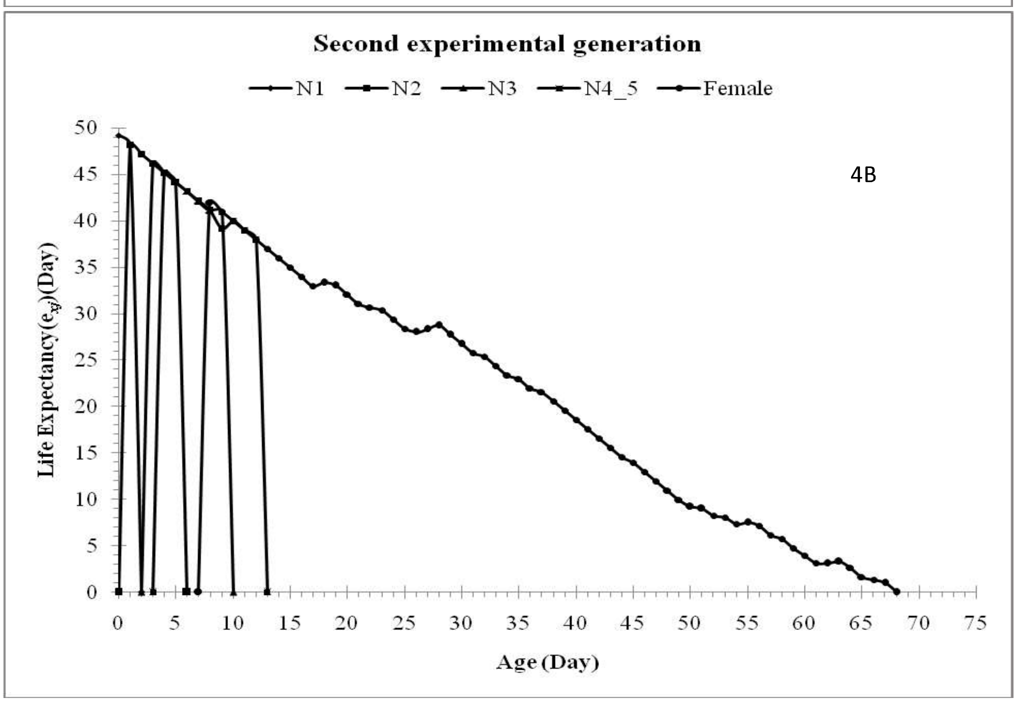


Fig. 4: Age-stage specific life expectancies (e_{xj}) of *M. persicae* reared on cabbage for two successive generations at ABPSTC, Pokhara. 4A- First experimental generation; 4B-Second experimental generation.

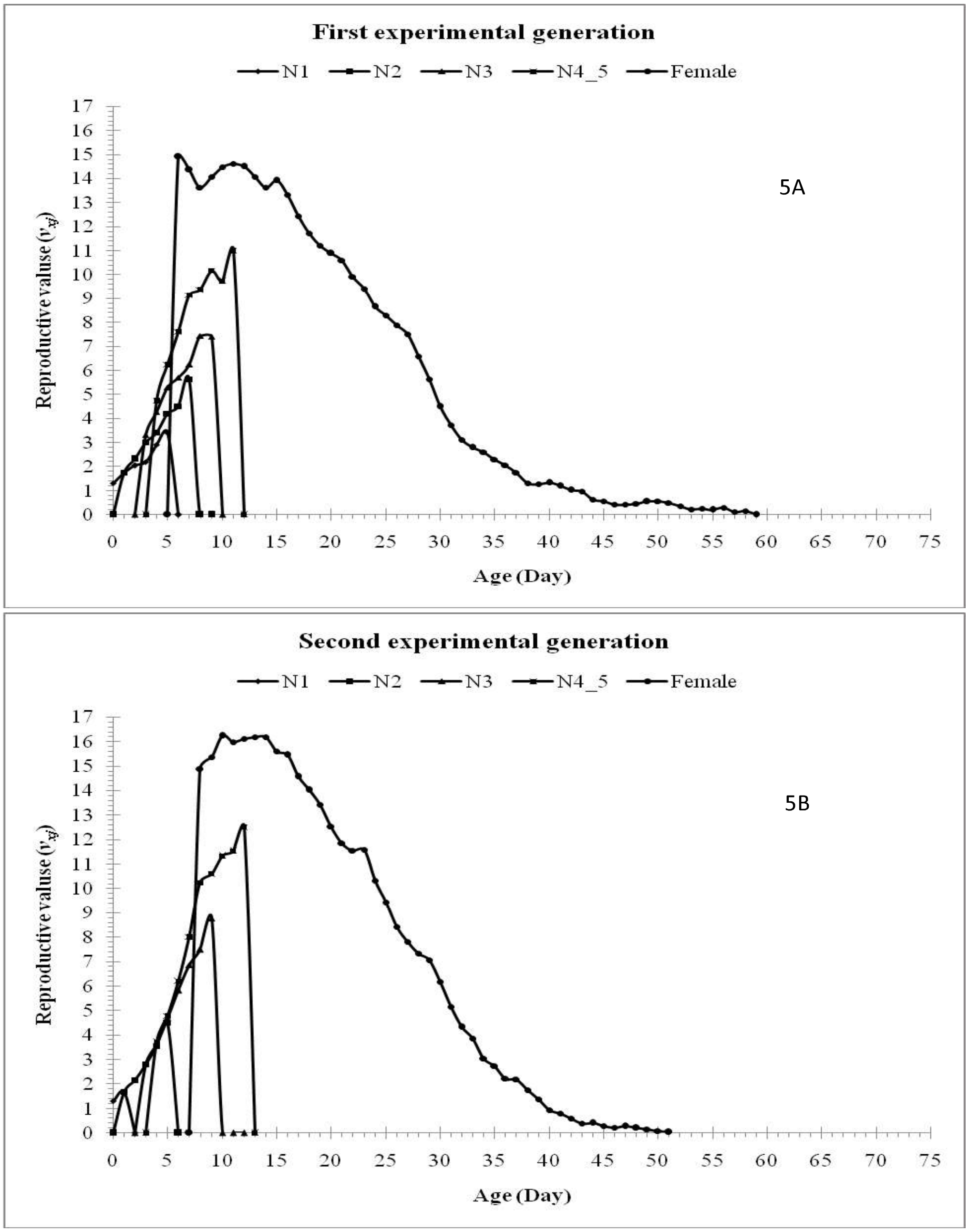


Fig. 5: Age-stage specific reproductive values (v_{xj}) of *M. persicae* reared on cabbage for two successive generations at ABPSTC, Pokhara. 5A- First experimental generation; 5B-Second experimental generation.

The life table parameters of *M. persicae* differed between two generations. This may be due to change in temperature and relative humidity as these experiments were conducted in indoor ambient condition and there were significant difference in temperature and relative humidity regime between two generations (Davis *et al.*, 2006). The intrinsic rate of increase of a population under different temperature and humidity is valuable in predicting population performance in field condition and useful to design IPM strategy against this pest. Further, it opens new dimension to carry out similar experiment under laboratory and field situations to investigate effects of temperature, relative humidity and truly apply such findings for the benefit of commercial cabbage growers.

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