



Full Length Article

Comparative Demographic Traits of the Whitefly (*Bemisia tabaci*) B Biotype against different Host Plants

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Abstract

The sucking pests, especially whitefly, have damaged various fields and fruit crops across the globe. The study of life-history is of prime importance to monitor the dynamics for preference of a species to its host. This study tested the prevalence and preference of a whitefly species, *Bemisia tabaci* (Gennadius) B biotype (Hemiptera: Aleyrodidae) on tomato, cotton, pepper, and okra as hosts using age-stage two-sex life table. Results revealed the highest pre-adult developmental duration, survival rate, and fecundity on tomato while the lowest values on okra. Population parameters such as the net reproductive rate (R_0), intrinsic rate of increase (r), and finite rate of increase (λ) were demonstrated longer on cotton and tomato compared to much lower R_0 , r , and λ on pepper and okra. Okra responded significantly differently in the case of the mean generation time, T among all tested genotypes. These findings suggest the possibility of summer vegetables as more favorable hosts for *B. tabaci*.
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Keywords: Host plants; Biology; Fecundity; Longevity; Survival; Whitefly

Introduction

The whitefly, *Bemisia tabaci* B biotype (Gennadius) (Hemiptera: Aleyrodidae) have become a significant pest for a wide range of agricultural and ornamental plants since the last two decades (Oliveira *et al.* 2001; Naranjo *et al.* 2009). The whitefly damages the crop in two ways; one by the nymphs by sucking cell sap and producing honeydew; and the other by the transmission of various viruses to other plants (Jones 2003; Naranjo *et al.* 2009). The females lay eggs in the groups of 30–40 eggs in patches (Martin *et al.* 2000). The first instar larvae move to short distances to acquire food sources, but other instars are immobile and are stick to the leaf surface. Their abilities of rapid development, high fecundity, and suitability to adverse living conditions hinder the successful control (Barro *et al.* 2011; Lu *et al.* 2012). The un-planned, unnoticed and rigorous use of insecticides has not only created resistance against a broader range of pesticides but triggered many health and environment-related problems. The previous studies only reported the population abundance and management practices of lepidopterous pests, neglected the

population ecology of sucking pests (Men *et al.* 2005). As a result, sucking pests especially *B. tabaci* overwhelmed the management tactics and became a member of the major pest complex (Wu *et al.* 2002; Akram *et al.* 2013). As a huge gap has been created, which needs to be addressed by thoroughly understanding the behavior of sucking pests.

The nutritional quality of the host affects the biological parameters of polyphagous insect species (Askoul *et al.* 2018; Farooq *et al.* 2018, 2020). The developmental duration, fecundity, and longevity of *B. tabaci* are also strongly influenced by the type of host plant with high nutritional qualities, it provides more food, shelter, and space for ovipositing (Lorenzo *et al.* 2016). Insects recognize the food quality of a host plant through various stimuli that help to locate the host plants. Different morphological leaf characters such as hair density, shape, and color determine the attractiveness to a pest species (Oriani *et al.* 2011). The nutritional effects of host plants in various species of whitefly have been studied earlier but very little information is available about the life history parameters of *B. tabaci* based on age-stage two-sex life table.

The awareness about the life and biology of a pest is

the crucial factor determining its feeding potential. A pest behaves differently at each age and stage in various environments or living conditions (Chi 1990). The implementation of life tables offers a firm understanding of the developmental and reproductive potential of a particular pest under changing living conditions that can be implied in the manipulation of future management strategies (Musa and Ren 2005). Most of the studies utilized traditional female-specific life tables (Birch 1948; Khan *et al.* 2017) to generate life tables of insect pests under different environmental situations. A female-specific life table does not provide an accurate picture of the population projection of an insect by neglecting the contribution of males and stages in population growth (Birch 1948). The most advanced form of life table is the age-stage two-sex life table developed by Chi (1988) and Chi and Liu (1985) which considers stage differentiation and offers a nearly appropriate estimate of the future population in varying conditions. Unfortunately, the use of the age-stage two-sex life table remained underemphasized to study the biology of sucking pests due to inappropriate handling of a large amount and misinterpretation of data (Samih *et al.* 2014). Awareness on a large scale is needed to encourage scientists to use advanced tools while studying population ecology.

The present studies were aimed to investigate the possibilities of the success of *B. tabaci* on different host plants by taking into account the developmental duration, fecundity, and life table parameters with the help of age-stage two-sex life table. This study considered tomato, cotton, pepper, and okra genotypes to compare the success of *B. tabaci* and also performed a population projection analysis to evaluate the future population potential within the specified time.

Materials and Methods

Host plants and *Bemisia tabaci* culture

Four different host plants (tomato, cotton, pepper, and okra) were used in these experiments. The 30 seeds of each genotype were sown in 120 plant pots having 25 cm diameter filled with compost and perlite substrate and placed under glasshouse conditions ($25 \pm 3^\circ\text{C}$, 60 ± 5 R. H. and photoperiod 16: 8 h L: D) (Azimi *et al.* 2013). Forty pairs of wild *B. tabaci* adults were initially collected with an aspirator from research farms of Ayub Agricultural Research Institute, Faisalabad, Pakistan and released onto host plants at 4–5 leaf stage placed in a cubic cage ($30 \times 30 \times 30 \text{ cm}^3$) covered with a fine mesh net (Guo *et al.* 2014). The plants were watered and fertilized regularly throughout the study period for their proper growth. Three generations of *B. tabaci* were raised on each of the tested host plants under the same conditions before being used for experimentation and to reduce the effect of wild hosts.

Life table studies

For assessing developmental duration, 1-day old adults collected from culture were shifted on a potted plant placed under the same lab conditions. After 24 h, the leaves were turned to observe eggs with a 10X hand lens, and adults were removed. A total cohort of 50 eggs was used per treatment. Each egg was circled with the help of a fine non-toxic marker, and all other eggs on leaves were gently removed to maintain the purity of marked leaves. The maximum of five leaves was retained on one plant, each leaf having one egg. Small-numbered tags were hanged around the leaf petiole to indicate each treatment. The same procedure was repeated for first instar nymphs soon after they settled on the leaf. After the establishment of the first-instar nymph on the leaf, nymphs do not move until the emergence of adults. Moulting and development of each nymph were observed daily with a 10 X hand lens. The leaves were detached at the pupal stage and shifted to plastic cages ($13 \text{ cm} \times 3 \text{ cm}$) covered with a fine mesh net. After the adults' emergence, both sexes were observed daily for oviposition and longevity studies.

Statistical analysis

The data were analyzed using the TWSEX-MSChart (Chi 2013). The bootstrap technique with 100,000 replications was applied for the estimation of mean and standard errors for each treatment (Efron and Tibshirani 1993). The Origin 2018 was used to draw the figures. The following parameters were calculated according to respective equations.

The age-specific survival rate (l_x) and age-specific fecundity (m_x) were calculated as:

$$l_x = \sum_{j=1}^k s_{xj}$$

$$m_x = \frac{\sum_{j=1}^k s_{xj} f_{xj}}{\sum_{j=1}^k s_{xj}}$$

Where, k exhibits the number of stages.

The net reproductive rate (R_0) was computed as:

$$R_0 = \sum_{x=0}^{\infty} l_x m_x$$

The intrinsic rate of increase (r) with age indexed from 0 was corrected by the Euler-Lotka equation (Goodman 1982):

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

The following equation was used for the finite rate of increase (λ):

$$\lambda = e^r$$

The mean generation time was demonstrated as

$$T = \frac{\ln R_0}{r}$$

The life expectancy (e_{xj}) was determined as:

$$e_{xj} = \sum_{i=x}^{\infty} \sum_{y=j}^{\beta} s_{iy}$$

Where, s_{iy} shows the probability of survival of each individual of age x and stage j to age i and stage y by assuming $s_{xj} = 1$.

The reproductive rate (v_{xj}) was assessed according to (Tuan *et al.* 2014a, b).

$$v_{xj} = \frac{e^{r(x+1)}}{s_{xj}} \sum_{i=x}^{\infty} e^{-r(i+1)} \sum_{y=j}^{\beta} s_{iy} f_{iy}$$

Population projection and confidence interval

The population growth of *B. tabaci* on four different host plants was projected from life table data based by the method of Chi and Liu (1985) and Chi (1990) using TIMING-MSChart (Chi 2017). The bootstrap method with 100,000 repeats was used to determine the variability in population growth of life table parameters. 2.5th and 97.5th percentiles were generated by bootstrap for R_0 and λ .

Results

Developmental time

The results revealed that the incubation period of *B. tabaci* significantly differed among tested host plants (Table 1). The total pre-adult developmental duration was noted significantly longer on okra than raised on other hosts, while shorter pre-adult developmental duration was observed on tomato. The immature survival rate was recorded higher on tomato and lowest on okra, which significantly differed from other hosts. Female adult longevity remained the greatest on okra and tomato, varying considerably from cotton and pepper. On the other hand, male adult longevity was found to be the longest on tomato whereas the shortest on okra. The results show that females live longer than males. The total longevity on okra was found significantly higher than tested host plants. These results express the suitability and unsuitability of *B. tabaci* on various host plants.

Fecundity and population growth parameters

The adult pre-ovipositional periods (APOP) and total pre-ovipositional period (TPOP) (Table 1) were estimated significantly longer on okra than other hosts. The feeding of *B. tabaci* on different host plants reflects that the shortest oviposition duration and the lowest fecundity were recorded on pepper and okra, and the highest fecundity on tomato and cotton, respectively. The same trend was also observed for daily-maximum and life-long fecundity. Based on the mean comparison, results showed that tomato was more

susceptible to *B. tabaci* than other hosts.

Age stage-specific survival rate (s_{xj}) showed the probability for the survival of freshly laid eggs of *B. tabaci* to each age-stage unit (Fig. 1). The highest survival curve for adult female and male on each cultivar was 0.48 and 0.26 (cotton), 0.34 and 0.28 (pepper), 0.30 and 0.26 (okra), 0.46 and 0.4 (tomato). These values are statistically at par with pre-adult survival rate (%) of 0.74, 0.62, 0.56 and 0.86 respectively (Table 1). The curves not only explain the survivorship but also have overlapping curves showing stage discrepancy, which is an important feature for insects (Fig. 1). The consistency in data represents that adult *B. tabaci* emerged earlier when reared on tomato and survives longer. The l_x , m_x and $l_x m_x$ for *B. tabaci* reared on each host plant species showed that the highest peak of m_x was noted on tomato at age of 28 d and the lowest peak was on pepper at the age of 32 d (Fig. 2).

The age-stage specific life expectancy (e_{xj}) presents the expected life span of *B. tabaci* on test hos plants (Fig. 3). The life expectancy of freshly laid eggs on each host plant species was 27.06, 27.1, 27.76, and 27.92 d, respectively which is precisely similar to mean longevity of the whole cohort on each host species, respectively. Life expectancy (e_{xj}) was decreased with the advancement in age due to *in vitro* condition which prevented the *B. tabaci* from harsh environmental field conditions. The age-stage specific reproductive value (v_{xj}) of *B. tabaci* illustrates the contribution of individuals of age x and stage j to the future population (Fig. 4). The reproductive value of *B. tabaci* at the egg stage was almost equal to the finite rate of increase in each host species. The highest reproductive peak of females was observed on tomato at the age of 20 d, while the reproductive peak for pepper was the lowest and found at later age of 26 d. The lower reproductive peak on pepper showed a moderate population increase.

The net reproductive rate R_0 , intrinsic rate of increase r , and finite rate of increase λ exhibited the lowest and mean generation time T the longest on okra (Table 2). Controversially, *B. tabaci* reared on tomato revealed the highest R_0 , r and λ and shortest T as compared to other host plants.

Population projection and uncertainty

The population was projected highest on cotton and expected to increase 25990.63 individuals at the age of 60, whereas okra predicted the lowest population size of approximately 544.316 individuals at the end of 60 d (Fig. 5). The variability in the total population size traced at 60 d projected from the 2.5th and 97.5th percentiles of the finite rate, and the net reproductive rate is demonstrated (Fig. 6).

Discussion

Developmental and population parameters of insects are affected by different biological, chemical, or physical traits such as plant phenology and secondary compounds. The

Table 1: Developmental duration, longevity, and fecundity of *Bemisia tabaci* reared on different host plant species

	Host Plant Species							
	n	Tomato	n	Cotton	N	Pepper	n	Okra
Developmental duration (d)								
Egg	48	3.98 ± 0.11d	46	5.04 ± 0.08c	44	5.91 ± 0.11b	45	6.49 ± 0.11a
N1	47	3.43 ± 0.08c	46	3.65 ± 0.07b	41	3.66 ± 0.09b	42	4.02 ± 0.11a
N2	46	2.57 ± 0.07c	44	2.68 ± 0.07c	39	3.54 ± 0.08b	40	3.8 ± 0.1a
N3	45	2.42 ± 0.07d	40	2.6 ± 0.08c	36	3.56 ± 0.09b	36	4.14 ± 0.12a
Pupa	43	3.47 ± 0.08c	37	3.86 ± 0.14b	31	5.61 ± 0.11a	28	5.61 ± 0.17a
Total pre-adult	43	15.88 ± 0.16d	37	17.81 ± 0.21c	31	22.35 ± 0.21b	28	23.93 ± 0.33a
Pre-adult survival rate (%)		0.86		0.74		0.62		0.56
Adult duration (d)								
Female adult longevity	23	18.17 ± 0.29a	24	17.62 ± 0.26b	17	17.47 ± 0.21b	15	18.2 ± 0.26a
Male adult longevity	20	11.6 ± 0.23a	13	10.31 ± 0.36b	14	10.5 ± 0.25b	13	9.38 ± 0.27c
Total longevity	43	31.02 ± 0.49c	37	32.86 ± 0.68b	31	36.68 ± 0.72a	28	38.04 ± 0.96a
Fecundity								
APOP		2.78 ± 0.13b		2.58 ± 0.1b		2.29 ± 0.11c		3.13 ± 0.17a
TPOP		18.26 ± 0.21d		20.54 ± 0.31c		24.82 ± 0.33b		27.33 ± 0.51a
Oviposition days		12.65 ± 0.23a		12 ± 0.27b		11.82 ± 0.27b		11.73 ± 0.32b
Fecundity (nymphs/female)		122.7 ± 2.74a		115.21 ± 1.79b		60.12 ± 0.76d		66.07 ± 2.16c
Daily maximum		19		16		12		11
Life-long maximum		149		127		65		83

Where, N1= 1st Nymphal instar, N2= second nymphal instar, N3= 3rd nymphal instar; TPOP=Total pre-ovipositional period; APOP=Adult pre-ovipositional period. Values are mean ± S.E; Means within rows followed by the same letter are not significantly different. Standard errors were measured by 200,000 bootstrap resampling

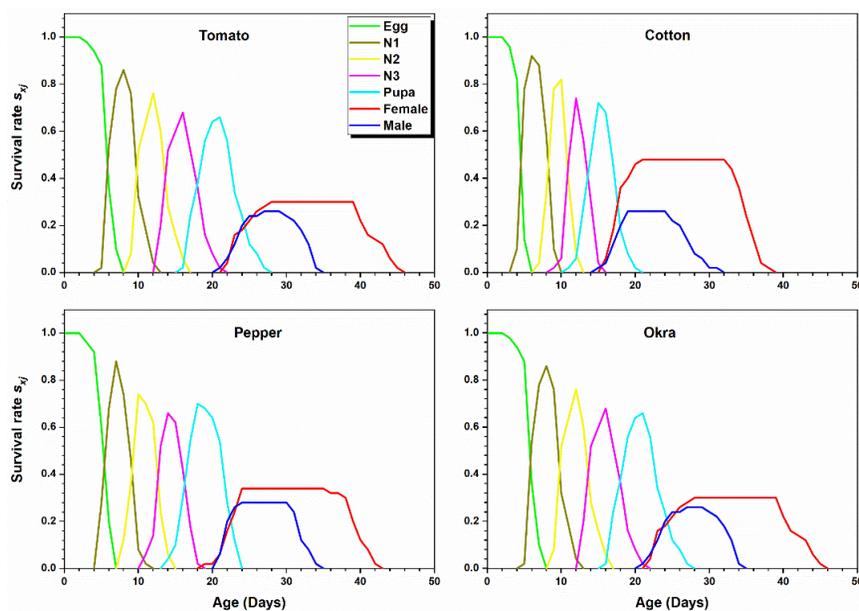


Fig. 1: Age-stage specific survival rate (s_{xj}) of *B. tabaci* reared on four host plant species

consumption potential of a pest is generally evaluated by developmental or behavioral responses (Phelan *et al.* 1995; Awmack and Leather 2002; Lee 2007). The use of life tables in determining these responses proved a useful tool to assess the relative acceptance or rejection of host plants by an insect species. Age-stage, two-sex life table has gained much insight among entomologists to evaluate the resistance of different plant genotypes against insect pests and to forecast future pest population peaks compared to female-specific life table (Morris and Miller 1954; Ying *et al.* 2012). This study also used the age-stage, two-sex life table to assess the plant resistance in four different host plants against *B. tabaci*.

Earlier researchers have reported the effect of host plant species on the development, survival, and fecundity of *B. tabaci*. The present study results demonstrated that pre-adult developmental duration was shorter when *B. tabaci* reared on tomato and cotton compared to other hosts. Statistical non-significant differences in population growth of *Bemisia argentifolii* Bellows & Perring were observed on cotton, cantaloupe, and pepper cultivars (Nava-Camberos *et al.* 2001) whereas fluctuating differences were observed when studying the population parameters of *B. argentifolii* on two cultivars of hibiscus (Liu and Stansly 1998). The pre-adult development of *B. tabaci* varied significantly among soybean, cowpea and garden bean (Musa and Ren

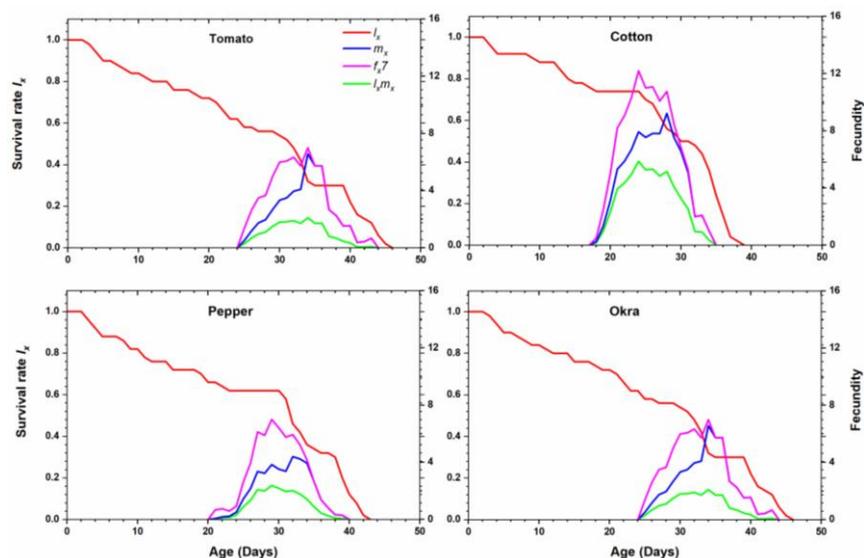


Fig. 2: Age-specific survival rate (l_x), age-stage specific fecundity (f_{xj}), age-specific fecundity (m_x) and age-specific maternity ($l_x m_x$) of *B. tabaci* reared on four host plant species

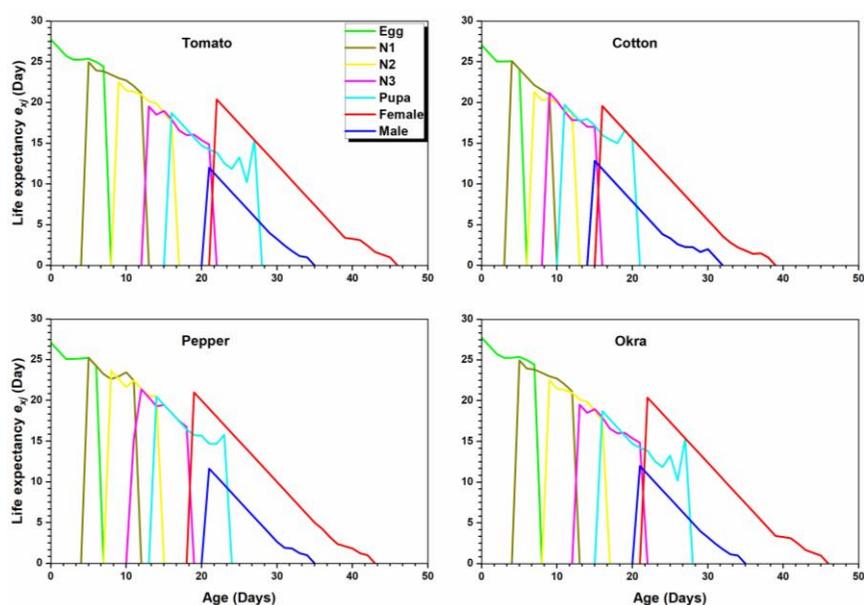


Fig. 3: Age-stage specific life expectancy (e_{xj}) of *B. tabaci* reared on four host plant species

2005). In another study, bean cultivars were found more resistant against whitefly, *Trialeurodes vaporariorum* (West.) (Hemiptera - Homoptera: Aleyrodidae) compared to soybean (Campos *et al.* 2003).

Life history parameters of *B. tabaci* are affected by host quality, trichome density, and nutritional value of host plants. Mostly, plant species with hairy leaves are preferred by the insects for feeding and as a site for egg holding (Butler *et al.* 1991; McAuslane 1996). The resistant cultivars may produce particular kinds of proteins or boost the chlorophyll content to avoid the pest attack and triggering

the resistance process (Smith 2005; Bernardi *et al.* 2012). The present study results demonstrated that pre-adult mortality percentage remained the highest on okra which depicts unfavorable population growth for *B. tabaci*. Male, female and total longevities were found to be significant among tested host species.

Adult pre-oviposition period (APOP), total pre-oviposition period (TPOP), and fecundity are essential parameters in assessing the potential of an insect pest on specific host plants (Awmack and Leather 2002; Azimi 2016). TPOP is often preferred over APOP; it includes the

Table 2: Population growth parameters of *Bemisia tabaci* on different host plant species

Parameters	Host plant Species			
	Tomato	Cotton	Pepper	Okra
R_0 (offspring/individual)	56.45 ± 6.17a	55.29 ± 5.79a	20.43 ± 2.85b	19.81 ± 3.06b
T (d)	23.91 ± 0.15d	25.71 ± 0.19c	30.52 ± 0.25b	32.85 ± 0.33a
r (d ⁻¹)	0.1684 ± 0.0049a	0.1558 ± 0.0044a	0.0985 ± 0.0048b	0.0905 ± 0.005b
λ (d ⁻¹)	1.1834 ± 0.0058a	1.1687 ± 0.0051a	1.1035 ± 0.0053b	1.0947 ± 0.0054b

Where R_0 =Net reproductive rate; T =Mean generation time; r =Intrinsic rate of natural increase; λ =Finite rate of increase. Values are mean ± S.E; Means within rows followed by the same letter are not significantly different. Standard errors were measured by 200,000 bootstrap resampling

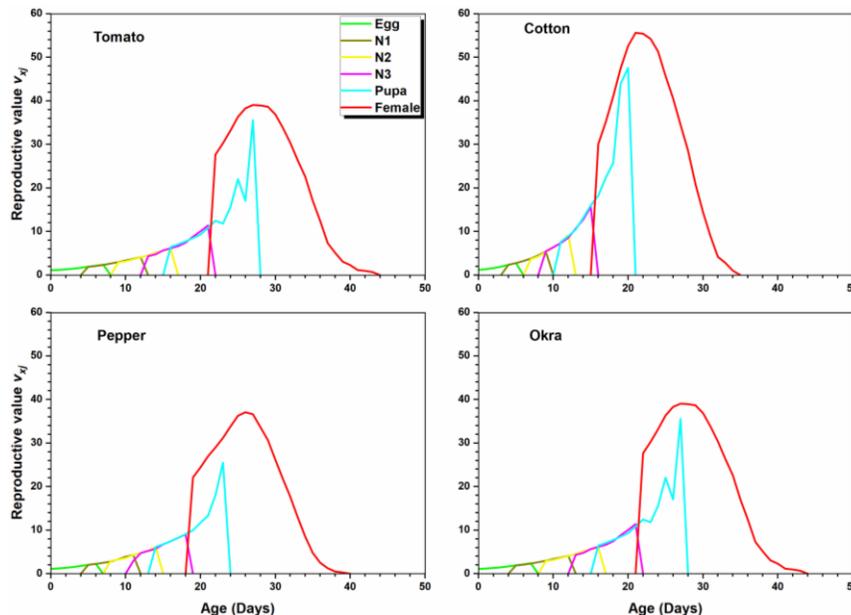


Fig. 4: Age-stage specific reproductive rate (v_{xj}) of *B. tabaci* reared on four host plant species

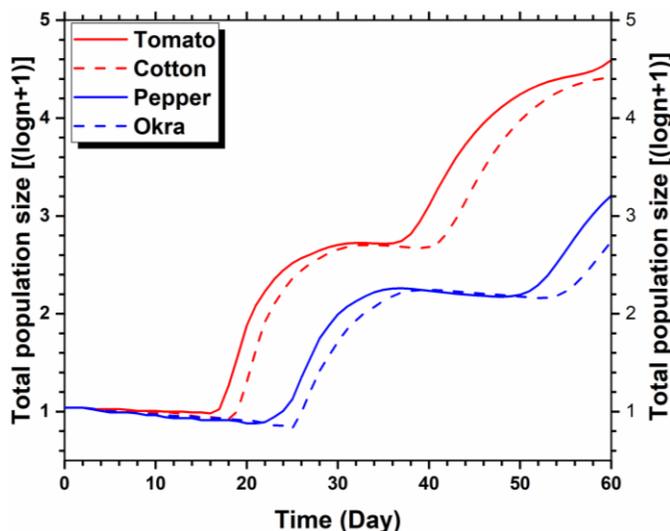


Fig. 5: Comparison of population projections for *B. tabaci* reared on four host plant species, based on the age-stage, two-sex life table

influence of pre-adult developmental duration on growth rate (Gabre *et al.* 2005). In present studies, APOP and TPOP differed significantly among tested host species. Okra generated the highest APOP and TPOP. The female

fecundity of *B. tabaci* observed on three host species (soybean, cowpea and garden bean) was 160.85, 153.07 and 98, respectively (Musa and Ren 2005). Salas and Mendoza (1995) reported that the egg incubation period of sweet-

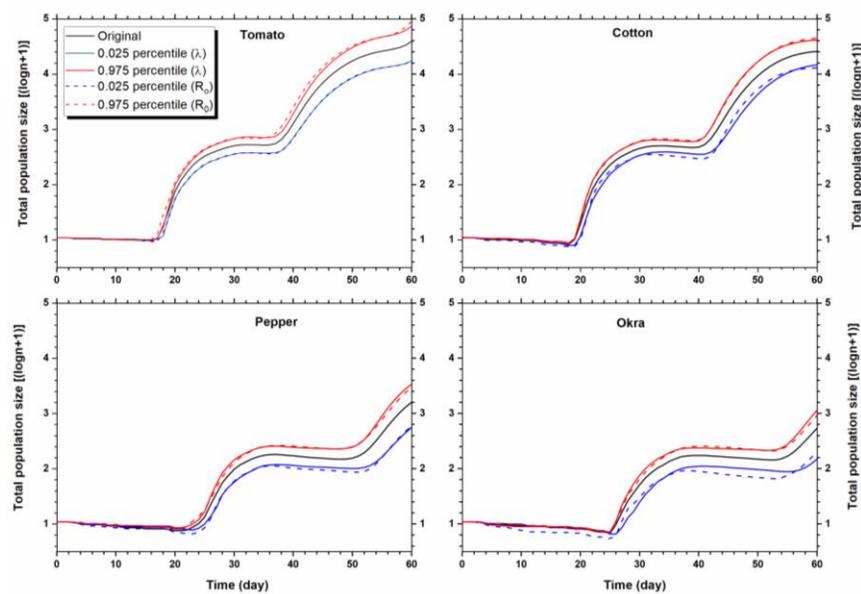


Fig. 6: Population projection of *B. tabaci* reared on four host plant species by using the life tables of the original cohort, the cohorts constructed based on the 2.5 and 97.5% percentiles of finite rate (λ) and net reproductive rate (R_0)

potato whitefly varied from 7.3, 4.0, 2.7, 2.5 and 5.8 for the first instar to the pupal stage, respectively. Female and male longevities were recorded as 19.0 and 19.4 days. The female fecundity remained high 194.9 with an 86.5% survival rate.

The population parameters present a brief idea about the influence of host plants on the population growth rate of a pest insect. The most crucial population parameters include the net reproductive rate (R_0), mean generation time (T), intrinsic rate of increase (r) and the finite rate of increase (k). The higher values of the population parameters except mean generation time exhibit a large population size (Goundoudaki *et al.* 2003). The significant differences in these population parameters were demonstrated by two biotypes of *B. tabaci* reared on *G. hirsutum* L. and *Brassica napus* L. (Samih *et al.* 2014). Musa and Ren (2005) reported that based on population parameters, rapeseed and cotton offered slow development of *B. tabaci* as compared to soybean. Kakimoto *et al.* (2007) presented that r and R_0 values of *B. argentifolii* were 0.168 and 185.1; 0.153 and 130.7; 0.143 and 73.1 and 0.110 and 36.1 on eggplant, cucumber, sweet pepper, and tomato, respectively. In present study, the population parameters were significantly different when *B. tabaci* reared on alternative host plant species. The higher net reproductive rate was observed on tomato and lower on okra. The intrinsic rate and the finite rate of increases were found higher among tomato and cotton as compared to other host species. Nonetheless, in contradiction to these findings, negative response of different cotton cultivars against *B. tabaci* has also been reported (Chandi and Kular 2014; Azimi 2016; Pessoa *et al.* 2016).

Population projection helps in understanding any change in stage structure based on life table data (Chi 1990;

Reddy and Chi 2015). The time of stage emergence of a population can be depicted by the concept of population projection and nowadays it is being used in various pest management strategies (Chi 1990). In a well-structured integrated pest management (IPM program), it is crucial to know about the age-stage specific consumption by a pest, which helps in devising a comprehensive pest control strategy (Huang *et al.* 2017). The population projection also helps in estimating the fluctuations in the feeding potential of the age-stage structure (Peng *et al.* 2016). The variability in growth was projected using life table data from 2.5th and 97.5th percentiles of finite rate of increase and the net reproductive rate. It was observed that with the advancement in time, the growth rate of *B. tabaci* stages was approximately equal to the intrinsic rate of increase on the natural logarithm scale (Huang *et al.* 2017).

Conclusion

The application of the age-stage two-sex life table to study the behavior of *B. tabaci* concerning different host plants yielded many valuable results. Longer fecundity and population parameters were observed on tomato specifically, with better nutritional qualities as compared to other host plant species. In summary, it was concluded that *B. tabaci* has successfully shifted to agricultural and horticultural crops and has been developed as a significant pest. Therefore, it was concluded that tomato is the most suitable host plant of *B. tabaci*, albeit, the pest also developed successfully on other hosts like cotton, pepper and okra. It indicates that these hosts might play an important role in the population development, survival and overwintering of *B.*

tabaci. Therefore, measures should be taken at all levels to combat the attack of this pest. Moreover, the biology of *B. tabaci* should also be studied using an age-stage two-sex life table in varying environmental conditions.

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Author Contributions

MF, MS designed and performed the experiment, BSK, SA and FH supervised the experiments and reviewed the manuscript, MRS analysed the raw data, US and MA helped in manuscript writeup.

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