

Development and Reproduction of Sweet Potato Whitefly *Bemisia tabaci* (Homoptera; Aleyroididae) on Four Vegetable Crops in Southern Sierra Leone

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Abstract

Bemisia tabaci is a polyphagous herbivore that feeds on a wide range of horticultural and ornamental crops cultivated under diverse ecological zones. In Sierra Leone, *B. tabaci* is found to infest a wide range of vegetable crops by directly feeding on phloem sap thereby inducing physiological disorders, and also serve as a vector to gemini viruses. Invariably the destructive feeding of *B. tabaci* affects the productivity and aesthetic values of vegetables and other horticultural crops and hence is considered a serious economic pest. A bioassay experiment was carried out by rearing *B. tabaci* populations on four vegetable crops under controlled laboratory conditions to determine its life table and demographic parameters. Results showed that the intrinsic rate of growth which measures the population size and growth pattern was highest for populations reared on tomato crops with the following values: r_m 0.145 female female⁻¹ day⁻¹, the gross reproduction rate (R_o), and finite growth rate λ were highest for population reared on tomato, correspondingly the development period from egg-adult emergence was shortest with a value of 26 d. Conversely, the computed demographical parameters r_m , λ and R_o for the population reared on sweet pepper were 0.106 female female⁻¹ day⁻¹ respectively, with a corresponding development period egg-adult emergence as 36d. The computed biological parameters for okra and garden egg varied with intermediary values between tomato and pepper host materials. The survivorship rates were quite significant for the smaller instars (Instars I-III) with over 80% surviving to pre-pupa and pupa stage for the populations reared for all the test materials. High mortality was noticed for the pre-pupa and pupa stages as their survival rates were significantly low compared to the high survival rates of the smaller

instars. Less than 50% of pupae failed to emerge to adults except for populations reared on tomato test materials where 52% emerged to adults. The study indicated tomato as the most suitable host among the four vegetable crops. Although life table and demographic parameters are invaluable information for forecasting pest populations and help in designing pest management efforts, further investigations such as the economic threshold and economic injury levels of *B. tabaci* population are requisite decision tools for sound pest management decisions of *B. tabaci* on these vegetable crops. The information obtained from this investigation would be quite relevant for extension service and pest management practitioners where mixed vegetable farming is a common practice.

Keywords

Bemisia tabaci, Life Table, Demographic Parameters, Host Plants, Biological Attributes, Population Dynamics

1. Introduction

Vegetables are an important category of crops that contain major sources of essential nutrients, namely vitamins and mineral salts, which are needed for the growth of a healthy population [1]. Besides, Normal *et al.* [2] observed that the cultivation and marketing of vegetables is a rewarding enterprise for smallholder vegetable growers in the rural, peri-urban and urban settlements which is considered an important sector for income generation in Sierra Leone. Importantly, vegetable farming is gender friendly, attracting a significant number of female folks to the vegetable value chain [3]. Among the numerous constraints affecting vegetable production, insect pests are considered serious biotic pressure affecting vegetable production in the field and in storage [4]. *Bemisia tabaci* is a polyphagous insect that feeds directly on the phloem sap of a wide range of vegetable crops and ornamentals thereby inducing physiological disorders such as stunted growth, yellowing of leaves and pre-mature ripening of fruits [4] [5]. These symptoms grossly reduce the aesthetic values of host crops, and consequently the economic values of the commodities are further reduced. Additionally, feeding of *B. tabaci* on host plants leads to the production of honey dews which serve as a substrate for the growth of fungi mounds and consequently, a point of attraction for ants as they feed on the secreted honey dews [6] making harvest more cumbersome. *B. tabaci* is further found to vector gemini viruses with devastating effects on the production of vegetable and ornamental crops, and some instances where infestations are significantly high can lead to a total collapse of entire vegetable fields [7]-[9].

A survey carried out by Mansaray *et al.* [10] on arthropod infestation on agricultural crops in Sierra Leone discovered that sweet potato whitefly *B. tabaci* affects a host of vegetable crops, cassava and sweet potato in diverse ecological zones. Their studies further indicated that *B. tabaci* is a serious vegetable pest in

Sierra Leone that affects vegetable crops in all seasons *i.e.*, both rainy and dry seasons, covering wide ecological zones. Infestation of crops by *B. tabaci* is not only limited to vegetable and ornamental crops, but widely affects cassava which is the second most important staple food in Sierra Leone [10]. Equally important, *B. tabaci* is found to be a vector virus disease known as cassava mosaic, a virus disease prevalent in cassava [9] [10].

The nutritional quality of the host affects the biological parameters of polyphagous insect species [11]. 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 [11]. Insects recognize the food quality of a host plant through various stimuli that help to locate the host plants. Different morphological leaf characteristics such as hair density, shape, and color determine the attractiveness of a pest species [12].

Heat Shock Protein (HSP) is a set of proteins that are regulated in response to fluctuation of temperature, chemicals and other hazardous substances creating a platform where agricultural pests can develop resistance when exposed to chemical pesticides and extreme temperatures [13]. Furthermore, the finding by Liu *et al.* [13] on the functional response of HSP indicated that *B. tabaci* showed the ability to respond to extreme temperatures by expressing various HSP which are regulated by heat shock factors as a result of stress which help *B. tabaci* to withstand extreme temperatures and hazardous chemicals facilitating their survivals in diverse ecological and climatic conditions. The authors further stressed that silencing these genes can reduce the survival rate of *B. tabaci* heat stress. Thorough understanding of the role of HSP can lead to innovative pest management strategies and a better understanding of the impact of climate change on agricultural systems [13].

The management of *B. tabaci* has been mostly centered around the use of chemical pesticides. Though these chemicals can obviously provide immediate results by reducing the pest population below the economic injury levels, the usage of these pesticides particularly broad types has devastating and disastrous effects when they are frequently used to manage insect pests. The most conspicuous side effects of indiscriminate and untimely use of pesticides are the killing of non-target pests including natural enemies and other beneficial insects like pollinators, environmental pollution with residual effects of pesticide residues in the environment, development of resistance genes in insects, pest resurgence and secondary pest outbreaks are quite obvious [14].

The use of synthetic pesticides is the most common management method of agricultural pests in Sierra Leone, despite the ability of these pesticides to reduce the pest population below the Economic Threshold (ET) and Economic Injury Level [13] [14]. However, there are myriads of side effects connected with their overuse chief among the killing of non-target pests including beneficiary insects such as pollinators that promote the fertility and production of agricultural crops and importantly natural enemies that serve as natural mortality factors that check

the pest population in space and in time [15]. Environmental pollution is quite obvious in the overuse of synthetic pesticides as a result of residues that persist in the environment which are translated along the food chain and trophic levels with a detrimental effect within the agro-ecological system [14]. Pest resurgence is another case associated with the overuse of synthetic pesticides. This phenomenon is noted in the sudden increase in pest population after the discriminating use of synthetic pesticides due to the killing of natural enemies that serve as natural mortality factors [16]. The absence of these natural factors leverages the possibility of a sudden increase in pest population. Another major side effect is that the outbreak of the secondary pest is quite obvious with the overuse of synthetic pesticides where minor pests assume major pest status [16]. The response to these negative effects has led to seeking options that are environmentally sustainable and cost-effective.

The use of life table and demographic parameters has been strongly advocated as a robust technique for a thorough understanding of pests biology and population dynamics and therefore considered an invaluable tool that can be utilized for predicting pest outbreaks and sound pest management strategy [4]. To develop a successful integrated pest management (IPM) program for its host crops, it is critical to understand the life-history parameters of *B. tabaci* notably the pre-selection of good biological control agents also depends on understanding the life-history parameters of the pest [4] [16]. Furthermore, some simulation models have been developed to predict the population dynamics of the sweet potato whiteflies *B. tabaci* whiteflies, and their natural enemies [15]. These models have proven useful in evaluating the biological control system [15] [17]-[19]. Life-history parameters are essential for population modeling [20]. In addition, host plants have important effects on development, mortality and fecundity rates in insect population dynamics [21]. Modeling of biological parameters including mortality and fecundity of insects provides invaluable insight on the timely application of biological control agents that target vulnerable immature stages of insects [20]. The population growth rate of insects, which incorporates development time, survivorship and fecundity, reflects the suitability of the host plant [22]. Yano [15] observed that differences in the population growth rates of a pest reared on different host plants influence the effectiveness of using natural enemies such as biological control agents. Equally important, the implementation of life tables offers a firm understanding of the developmental and reproductive potentials of particular pests under changing living conditions that can be implied in the manipulation of future management strategies [23]. Most of the studies utilized traditional female-specific life tables [24] 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 [24]. The most advanced form of life table is the age-stage two-sex life table developed [25] [26] 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 [27]. Awareness on a large scale is needed to encourage scientists to use advanced tools while studying population ecology.

The current study aimed to investigate the development and reproduction of *B. tabaci* on four host plants taking into account the developmental duration, fecundity, and life table parameters with the help of an age-stage two-sex life table. Four vegetable crops namely tomato, pepper, okra and garden egg were investigated to compare the development and reproduction of *B. tabaci*, and also performed a population projection analysis to evaluate the future population potential within the specified time. Despite *B. tabaci* being considered an economic pest for a wide range of horticultural crops, no information on its life table and demographic parameters is documented in Sierra Leone. This work bridges the knowledge gap on the population dynamics and growth pattern of *B. tabaci* reared on these vegetable crops. This study further laid a foundation as an initial step in forecasting its dynamics and formulating a sound pest management strategy for *B. tabaci* on vegetable crops. Thus, the findings of this study will provide a basis for the development of a sound pest management strategy for the control of *B. tabaci* against the test materials which are common vegetables grown in Sierra Leone by smallholder vegetable farmers and the data that would be derived from this work would serve as an empirical reference for extension and outreach service to smallholder farmers and for policy formulation for integrated vegetable pest management.

2. Materials and Methods

2.1. Background Information

The investigation was carried out at Lower Nursery of Horticulture Department at Njala University in southern Sierra Leone conducted in bioassay cages and improvised experimental dishes under standard laboratory conditions of $25 \pm 2^\circ\text{C}$, $75\% \pm 10\%$ Relative Humidity (RH) and photoperiod of Day: Light 12:12 in the months of May-July, 2023. These experimental conditions were maintained throughout the duration of investigation to evaluate the development and reproduction of *B. tabaci* populations on test materials namely tomato, sweet pepper, okra and garden egg.

2.2. Source of Whitefly *Bemisia tabaci*

The stock colony of *B. tabaci* population was established on cucumber and cabbage in potted containers and maintained in greenhouse. The second generation of the stock colony was used to infest the test materials.

Sources of Test Materials

Viable seeds of tomato, sweet pepper, okra and garden egg obtained from Seed Tech Company, Freetown, Sierra Leone were used in this investigation to determine the biology and life table parameters of *B. tabaci*. The viable seeds were

placed in petri dishes, soaked with water and covered with cotton wool to facilitate sprouting. The sprouted seeds were established in polythene bags with a well-manured and sterilized soils and then confined in bioassay cages of dimension 60 cm × 60 cm where these seedlings grew to a four-leaf stage under aforementioned experimental conditions.

2.3. Experimental Design and Treatment

The experimental design consisted of four treatments: tomato, sweet pepper, garden egg and okra arranged in a Completely Randomized Block Design (CRBC) with four replicates. Each replication of the test materials had sixteen polythene bags which were subjected to the same experimental conditions uniformly treated with well sterilized organic manures and water daily to a four-leaf stage which was considered appropriate for insect infestation.

Development and Survivorship

For development and survivorship of eggs and immatures, about three hundred undetermined sex of *B. tabaci* population were collected from the stock colony for infestation of test materials for 24 hrs to facilitate oviposition, thereafter the adults were removed and the amount of eggs oviposited counted under the microscope. The test materials were later placed in the growth chamber in the laboratory under the aforementioned environmental conditions to monitor the development and survival of eggs and immatures. The number of hatched eggs and nymphs was counted and recorded daily under the microscope. Leaves bearing the puparium showing a diagnostic feature of red eyes were enclosed in a petri dish covered with nylon cloth to facilitate the emergence of adults and determination of sex ratio.

2.4. Female Adult Longevity and Fecundity

The sex ratio of newly emerged adults from the cohort populations was separated and determined for each test materials. Each female was confined into a micro cage clipped to the undersurface part of the leaf and maintained in bioassay cages. The bioassay cages were maintained in an experimental chamber under the highlighted experimental conditions. The number of eggs laid *i.e.* fecundity everyday was counted and life span *i.e.* longevity of each female was recorded. To nullify the effect of honey dew secreted, old leaves are replaced with fresh ones every two days as a precaution for continuous egg production.

2.5. Life Table and Demographic Parameters

Life and fertility tables were calculated from cohort of eggs according to the method of Birch [24]. The death and survival rates q_x and s_x each day were recorded for all immature stages. The probability of surviving from birth (cohort eggs) to age X (l_x) for every immature stage was also calculated. The intrinsic rate of population increase r_m was calculated using Birch [24] [28].

$$r_m = \ln Ro/T$$

$$Ro = \sum l_x m_x$$

$$T = \sum x l_x m_x / \sum l_x m_x$$

l_x is the survivorship at the corresponding time, m_x is the number of female eggs laid according to sex ratio laid per female per day. The Gross Reproductive Rate (GRR) is the $\sum m_x$. The net reproductive rate (R_0) is the mean number of female progeny produced by a single female during its mean life span and was obtained by the equation: $R_0 = \sum l_x m_x$. This parameter expresses the per generation growth rate of the population and is related to discrete daily growth rate, the finite rate of increase (λ) ([28]). The finite rate of increase was calculated by the equation $\lambda = \exp(r_m)$ [29].

The Generation Time (GT) which is equivalent to the mean period elapsing between birth of parents and birth of offspring, and Doubling Time (DT) defined as the time required for the population to double its size [30] expressed by the respective equations $GT = \ln(R_0)/r_m$ and $DT = \ln 2/r_m$. The difference in r_m among the population was also analyzed using the Student-Neumann sequential test.

2.6. Data Analysis

Development and survivorship of egg and each nymphal stage are computed. Adult longevity and fecundity are analyzed among treatments of host plant species. Non-linear regression of longevity and fecundity were performed using SAS [31] [32]. All parameters were analyzed among treatments of host species using the General Linear Model (GLM) procedure of SAS; means were separated by the Duncan Multiple Range Test after a significant F-test at $p = 0.05$ [30].

3. Results & Discussion

Figure 1 Fecundity and survivorship rates of emerged female adults of *B. tabaci* reared on sweet pepper were determined with a cohort of ten newly emerged adults. A one-day pre-oviposition period was observed, fecundity commenced on the 2nd day after emergence with a value of 8 eggs·day⁻¹·female⁻¹, highest fecundity noted on the 7th day after adult emergence with an estimated fecundity rate of 12 eggs·day·female⁻¹, thereafter fecundity sharply declined throughout the lifespan of the female with last fecundity noted on the 15th day after adult emergence with a value of 2 eggs·female⁻¹·day⁻¹. A three-day post-oviposition period was observed whilst the last female died on the 19th day of emergence. 100% of the females reared on the host survived up to the 6th day, thereafter a reduction in survivorship was gradually noticed. Females laid more eggs in the 1st week after their emergence.

Figure 2 illustrates the survivorship rate and fecundity of a cohort of newly emerged *B. tabaci* adults reared on garden egg host plant. Two day pre-oviposition period was observed, and the highest oviposition period was recorded on the 8th day with an average number of 12 eggs·female⁻¹·day⁻¹, with a sharp decline on the 10th and 11th day. A two-day post oviposition period was noted, thereafter the last female died on the 21st day. 100% of the female adults lived up to the 8th day followed by a gradual decrease in subsequent days, whilst the survivorship gradually

decreased.

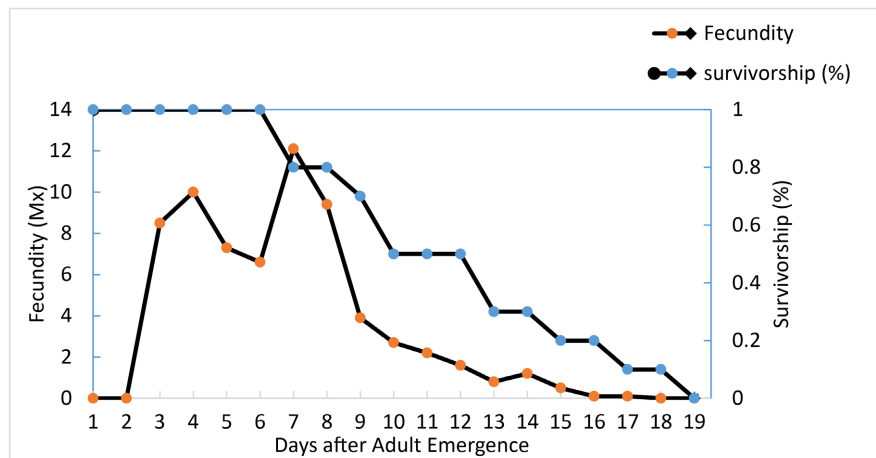


Figure 1. Fecundity and survivorship rate of emerged female adults reared on pepper host plant.

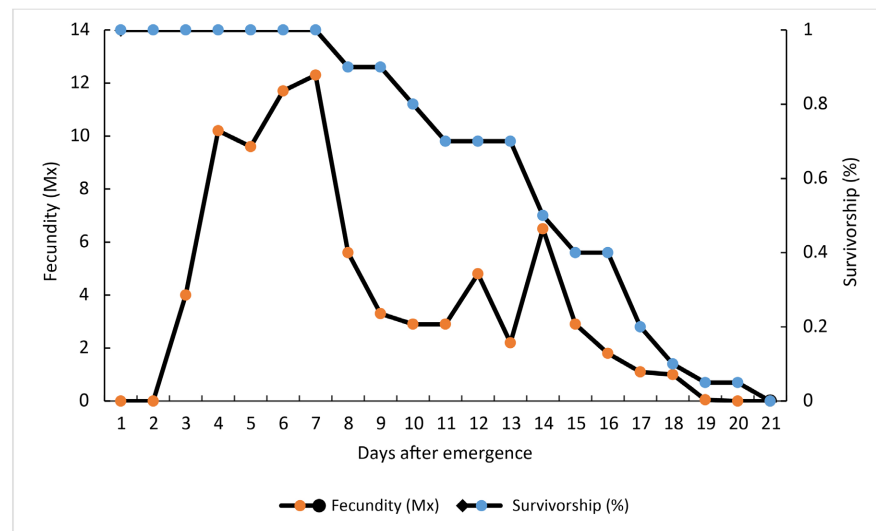


Figure 2. Fecundity and survivorship rate of Emerged Female Adults reared on Garden Eggs.

Figure 3 showed fecundity and survivorship rate of emerged female adults reared on tomato host plant. A one-day pre oviposition period was observed, highest fecundity observed on the 6th day with an average value of 10 eggs-female⁻¹.day⁻¹, followed by a sharp decline with slight peaks on 12th and 17th day with fecundity of 8 eggs-day⁻¹.female⁻¹ and 6 eggs-day⁻¹.female⁻¹ respectively after the emergence of the female adults. Average female longevity was recorded as 22 days. 100% of the insects survived up to the 6th day whilst survivorship gradually decrease up to the 22nd day when the last females died.

Figure 4 illustrates the fecundity and survivorship rate of *B. tabaci* reared on Okra host plant. Results indicated 2-day pre-oviposition period and 4-day post-oviposition period during the period of rearing. The highest fecundity was noticed

on the 7th day after emergence with a value of 9 eggs·female⁻¹·day⁻¹. 100% survival rate was observed up to 4 days after emergence whilst the last females survived up to the 16th day (**Figure 4**).

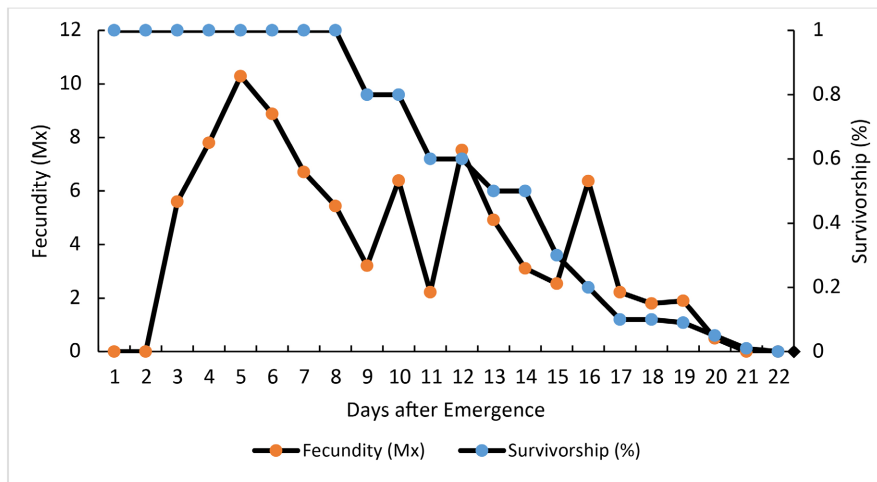


Figure 3. Fecundity and survivorship rate of emerged female adults reared on tomato host plant.

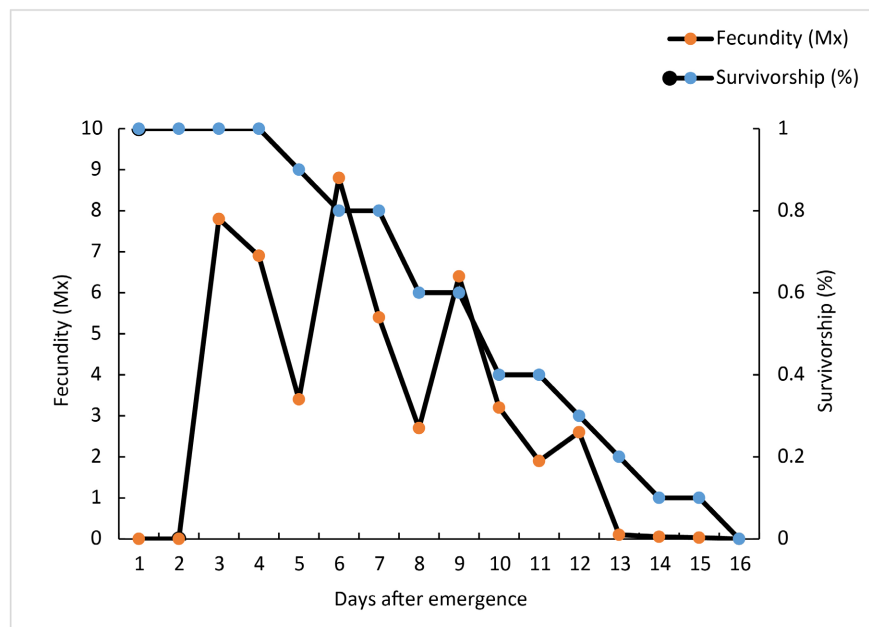


Figure 4. Fecundity and survivorship rate of female emerged adults reared on okra host plant.

Table 1 shows comparison of mean longevity and fecundity of cohorts of newly emerged females reared on four vegetable crops. Females reared on tomato host plant laid the highest number of eggs with an average of 8.74 ± 1.09 whilst the lowest number of eggs were recorded on sweet pepper with a value of 6.20 ± 0.40 . No significance differences were observed among the tomato, garden egg and okra at $p = 0.05$ level of significance (**Table 1**). Longevity period varied among the four

vegetable crops with the highest period recorded for insects reared on tomato with a value of 22.34 ± 4.56 days whilst the shortest period was significantly noted for females reared on sweet pepper 16.47 ± 2.88 (Table 1).

Table 1. Mean Longevity and Fecundity of *B. tabaci* reared on four vegetable crops (M \pm SE).

Vegetable Crops	Fecundity (Eggs Laid) (female ⁻¹ .day ⁻¹) (M \pm SE)	Longevity (Days) (M \pm SE)
Tomato	8.74 \pm (1.09)a	22.34 \pm (4.56)a
Garden Egg	8.27 \pm (1.17)a	21.04 \pm (3.88)a
Okra	6.91 \pm (0.48)ab	19.25 \pm (3.01)a
Sweet Pepper	6.20 \pm (0.40)b	16.47 \pm (2.88)b

Means in column with the same letter are not significantly different from each other at (p = 0.05) level of significance (Duncan Multiple Range Test).

The development period of *B. tabaci* eggs and immatures reared on four vegetable crops was monitored under standard laboratory conditions and results are presented in (Table 2). Results showed that the incubation period for the eggs reared on the test plants varied across the host plants with the least incubation period recorded for eggs reared on tomato host plant whilst the highest incubation period was recorded for sweet pepper. The values of incubation periods were not significantly different for tomato, okra and garden egg (p = 0.05) except for sweet pepper with a period of 7.82 days (Table 1). The development period for the nymphal stages (Instar1- IV) were not significantly different for the populations reared on the test materials at (p = 0.05), however the development period of pupae varied across the host plants. The pupae reared on the tomato plant experienced the shortest development period with a value of 5.01 days whilst the development period for pupae reared on sweet pepper was 8.66 days (Table 1). The development period from egg-adult significantly varied among the test materials with the longest period recorded for insects reared on sweet pepper with an average value of 37.81 days. No significant difference noted for insects reared on tomato and garden egg with values of 25.74 days and 26.11 days respectively (Table 1).

Table 2. Development Period (Days M \pm SE) of *B. tabaci* reared on four vegetable crops.

Vegetable Crops	Development Period (Days M \pm SE)						
	Egg	1 st Instar	2 nd Instar	3 rd Instar	4 th Instar	Pupa	Egg-Adult
Tomato	5.33a (\pm 0.22)	2.18a (\pm 0.09)	2.8a (\pm 0.19)	4.09a (\pm 0.39)	4.27a (\pm 0.19)	5.01a (\pm 0.09)	25.74a (\pm 1.09)
Garden Egg	5.92a (\pm 0.19)	2.23a (\pm 0.16)	3.10a (\pm 0.22)	4.51a (\pm 0.18)	4.37a (\pm 0.17)	5.08a (\pm 0.17)	26.11a (\pm 0.88)
Okra	6.24ab (\pm 0.57)	2.19a (\pm 0.11)	2.92a (\pm 0.14)	6.94a (\pm 0.35)	6.72a (\pm 0.32)	7.53ab (\pm 0.22)	30.92b (\pm 1.98)
Sweet Pepper	7.82b (\pm 0.38)	2.98a (\pm 0.09)	2.63a (\pm 0.13)	6.37a (\pm 0.16)	6.29 (\pm 0.19)	8.66b (\pm 0.31)	37.81c (\pm 1.07)

Means in column with the same letter are not significantly different from each other at (p = 0.05) level of significance (Duncan Multiple Range Test).

The survival rates of cohorts of *B. tabaci* population reared on the test materials from egg to adult emergence were monitored under standard laboratory conditions, and results are presented in (Table 3). The survival rates of the egg stage and smaller instars (Instar I-III) were significantly high for insects reared on the four vegetable crops with survival rates over 80% of eggs incubated on the host plants hatched into 1st Instars. Similarly, the survival rates for smaller immatures (1st-3rd instars) were significant high with over 90% of smaller 1st instars reared on tomato host plants developed into instar II. Similarly, high survival rates smaller instars were noted for garden egg, okra and sweet pepper respectively with value over 80% (Table 3). The survival rates of larger immatures Instar IV and the Pupae however varied across the test materials with the highest survival rate recorded for insects reared on garden egg with a value of 60.21% whilst the least survival rate for Instar IV was noted for insects reared on sweet pepper 40.23%. The survival rates for the pupa stage varied, the highest survival rate was recorded for tomato with a value of 52.34% and the least noted for pupae reared on sweet pepper with a survival rate of 36.31%. The overall survival rates for egg-adult emergence varied slightly for tomato, garden egg and okra, no significance difference in their values ($p = 0.05$) except for insects reared on the sweet pepper that showed a significant value of 38.12% (Table 3).

The demographic parameters of *B. tabaci* reared on four vegetable crops based on the calculation of Birch [24] are expressed in (Table 4). The intrinsic rate of increase r^m varied across the host plants with highest r^m recorded for insects reared on tomato with a growth value of 0.149 while the least value was observed for sweet pepper with r^m value of 0.106. The r^m values for insects reared on tomato and okra were 0.149 and 0.147 were not significantly different based on Jack Knife estimation). The finite rate of increase (λ) varied among the test materials and correspond closely with the intrinsic rate of increase (Table 4). The net female reproductive rate measured as R_0 varied across the host plants with the highest and lowest values recorded for insects reared on tomato and sweet pepper with values of 74.20 and 37.42 respectively (Table 4). The corresponding Generation Time (GT) were 28 days and 34 days respectively whilst the r^m for garden egg and okra were observed as 0.142 and 0.124 and a Generation Time (GT) of 29.38 days

Table 3. Survivorship rate (%) of *Bemisia tabaci* developmental stages.

Vegetable Crops	Survivorship rate (%)						
	Egg	1 st Instar	2 nd Instar	3 rd Instar	4 th Instar	Pupa	Egg-Adult
Tomato	89.32a	93.11a	90.04a	91.34a	54.34a	52.34a	55.27a
Garden Egg	87.54a	85.29a	83.66a	80.34a	60.21a	41.36b	53.06a
Okra	82.47a	85.10a	81.29a	83.56a	55.01ab	38.91c	49.27a
Sweet Pepper	84.01a	86.21a	83.26a	80.09a	40.23c	36.31d	38.21b

Means in column with the same letter are not significantly different from each other at ($p = 0.05$) level of significance (Duncan Multiple Range Test).

Table 4. Demographic Parameters of *B. tabaci* reared on four vegetable crops.

Host Cultivars	Intrinsic rate of increase (r^m)	Finite rate of increase (λ)	Net Reproductive Rate (R_o)	Td	Doubling Time (DT)	Generation Time (GT)
Tomato	0.149	1.160	74.20	28.73	4.65	28.00
Garden egg	0.142	1.153	64.89	29.23	4.88	29.38
Okra	0.124	1.132	56.31	32.34	5.58	32.50
Sweet pepper	0.106	1.115	37.42	34.23	6.53	34.17

and 32.50 respectively. The trend of Double Time (DT) corresponds closely with the Generation Time (GT) as indicated in **Table 4** with tomato > garden egg > Okra > sweet pepper.

Research efforts were geared towards investigating the development and reproduction of *B. tabaci* populations reared on four vegetable crops grown and marketed in Sierra Leone namely okra, sweet pepper, garden egg and tomato to determine the population projection and growth pattern of the pest. The population parameters present a brief idea of influence of host plants on population growth rate of an insect pest and the most crucial parameters include Net reproductive rate (R_o), the Intrinsic rate of growth (r_m), the finite rate of increase (λ), Doubling Time (DT) and Generation Time (GT). The results of the current study revealed that *B. tabaci* population reared on tomato plant indicated the highest growth rate of 0.149 female-female⁻¹·day⁻¹ and correspondingly 28.00 days was observed as development period from egg oviposition to emergence of adult. Contrarily, the least growth rate was recorded for *B. tabaci* population reared on pepper with a value of 0.106 female-female⁻¹·day⁻¹ and corresponding required 34.17 days to complete one generation. These results emphasized that suitable host supports high population size and shorter period to complete one generation This was reflected in this study as revealed by the population size of *B. tabaci* reared on tomato plants significantly higher as compared to the populations raised on the other test materials. [5] proposed that nutritional quality of host plants affects the biological parameters of polyphagous insect species. The authors studied *B. tabaci* B-biotype Bemisia argentifolii reared on four hosts namely eggplant, cucumber, sweet pepper and tomato identified eggplant the most suitable host and tomato the least preferred host unlike the findings in this investigations. It should be noted two different biotypes were used from different geographical locations which perhaps most probably reasons for preference of host. The dissimilarity of results underscores the fact that biotypes may differ in the choice of host materials as indicated for our studies and results of Tang & Tsai [5]. Besides nutritional quality, Macaulane [31] stressed the importance of morphological features as important criteria in contributing to high population dynamics of insects by underscoring that density of hair on leaves is preferred and attracted by insects for feeding as a site for protecting eggs for subsequent development into various immature stages. This invariably indicates that plant architecture and nutritional values are highly implicated in selecting host plants for egg oviposition and

subsequent development into nymphal and adult stages. The current investigation strongly supports this view based on the values obtained when *B. tabaci* adults were reared on the four host plants differing in physical architecture. The findings indicated that the biological parameters compared in relation to architecture of the test materials significantly differed which might have attributed to morphological features outlined namely the hairy leaves which were conspicuously visible on the tomato host plants as compared to the smooth leaves of sweet pepper and the other test materials. Studies conducted by Musa & Ren [23] on three bean species soybean, cowpea and garden bean revealed that soybean supported high population size than the cowpea and garden bean respectively. Similar view was advanced by Farooq *et al.* [11] by comparing the demographic parameters of whitefly populations reared on four host plants showed that the intrinsic growth rate r_m of *B. tabaci* reared on tomato, pepper, and okra were 0.1684, 0.0985, and 0.0905 females·female⁻¹·day⁻¹ respectively. These results are similar to the results obtained in this investigation, the r_m for populations reared on tomato are higher than okra and pepper respectively. Azimi [32] opined that pre-oviposition period, total oviposition period and fecundity are essential parameters in assessing the potential of an insect pests on specific host plants. This investigation revealed 2-day pre-oviposition period observed for population reared on all the test materials did not however differ irrespective the host plant. However, the fecundity and longevity of the females reared across the test materials varied with longest female longevity of 22.34 days recorded for population reared on tomato in contrast to population raised on sweet pepper of 16.17 days. Correspondingly fecundity of female adults indicated a trend: tomato > garden egg > okra > sweet pepper with values of 8.74, 8.27, 6.91 and 6.20 eggs·female⁻¹·day⁻¹ respectively. Interestingly, there seems to be a strong relationship between life span of female adults and fecundity, perhaps the most probably reasons are based on nutritional value as well as the architectural nature of the host plant. Several studies have indicated that host plant quality is the determinant of the fecundity of herbivorous insects. Components of host plant quality such as carbon, nitrogen and defensive metabolites directly affect potential and achieved herbivore fecundity. Tsai & Wang [5] stressed that identification of insect biology, host preference and behaviour are crucial to find economically and ecologically sustainable solutions to problems caused by herbivorous insects. Though analysis of nutritional constituent of major elements were not investigated in this current study, it is however assumed that the hairy nature of tomato leaves coupled with its nutritional values supposedly have served as stimuli for high fecundity and protracted longevity of the female adults as compared to the other test materials. Furthermore, Tsai and Wang [5] pointed out that the factors determining nutrient availability for growth and maintenance over a given period of development are the amount and type of food consumed and the efficiencies of utilization.

Designing pest management intervention has considered the use of life table parameters to identify the most vulnerable developmental stages prone to mortality or that suffer the highest mortality to make time-based intervention for

significant outcome. This study endeavoured to highlight the development periods and survivorship rates as indices to determine the suitability of the test materials to *B. tabaci* populations. The investigation showed that fertility of eggs incubated on the test materials was quite significant as over 80% of eggs oviposited hatched into 1st instars irrespective of the test materials. The incubation periods for the eggs were not significantly different, though. The findings further indicated that the percentage survival of smaller instars (Instars I-III) was quite significant with over 70% survivorship rates observed for smaller instars irrespective of the test materials. Mortality was high for larger instars namely the pre-pupa and the pupal stage respectively. For all of the populations reared on the test materials, survivorship rates were significantly low for pre-pupa and pupal stages strongly indicating that the later developmental stages encountered high mortality as compared to the early instars where the casualties experienced were relatively low. Results further showed that the pre-pupa and pupa stages were more vulnerable to mortality factors, in fact less than 50% of the pupa and pre-pupa (instar IV) populations reared on garden egg, okra and sweet pepper emerged into adult stage and only 52% of those that were reared on tomato host material which is considered the most suitable host emerged into adult. A similar trend was observed for the overall survival rate *i.e.* egg-adult emergence for *B. tabaci* population reared on tomato with a value of 55.27 %, implying that 55.27% of eggs oviposited on tomato transformed to adult stage whilst 38.21% eggs oviposited on sweet pepper emerged. The survivorship rates for okra and garden egg were not significantly different from the population that survived from tomato that recorded the highest survivorship. The current studies indicated high survival rates of eggs and smaller immatures (Instars I-III) inversely high mortality observed for larger instars leading to lower percentage of adult emergence.

Plants store chemical defenses that act as toxins that influence complete metamorphosis of herbivorous insects, the fitness of herbivorous insects can be easily compromised by these chemicals from egg oviposition to adult emergence [21]. Kakimoto *et al.* [33] proposed that the fast decaying fitness of an immature insect does not only lead to high mortality but also to other adverse effects, such as reduced growth, slow feeding, delayed development. This study proposed the high survival rates of early immatures are due to the fact that early instars are actively metabolic and much able to withstand the toxins through the process of sequestration as an active mechanism to reduce the potency of toxins. On the contrary, the inactiveness of the pre-pupal and pupal stages during transformation are much prone to these toxins leading to high mortality of later instars like pre-pupal and pupa stages. The current study compromised with the results of Kakimoto *et al.* [33] where demographic parameters of Silverleaf whitefly *Bemisia argentifolii* were compared. The authors observed that the smaller instars experienced high survival rates relative to larger instars when their populations were reared on vegetable host plants. The authors observed > 80% survival rate of smaller immatures while the of pre-pupal and pupal stage suffered high casualties in current study is

in line with the results of Kakimoto *et al.* [33] with high mortality rate observed in the larger instars as compared to early instars. The less suitable host has prolonged development period reducing the fitness of the immature to adult emergence.

Selective pesticides targeting vulnerable developmental stages of *B. tabaci* has been proven to be quite effective in managing *B. tabaci*. Findings of Rattan *et al.* [34] indicated that selective use of Cyantraniliprole is observed to effectively manage *B. tabaci* population as the insecticides caused feeding cessation during nymphal and adult stage respectively. However, their studies further proved that for effective use of these insecticides an optimal dosage threshold is required where feeding cessation occurs most rapidly and effectively. In a sustainable pest management efforts, optimal application rate and timing of application targeting vulnerable stages is of utmost importance to avoid pest resistance and could be a useful tool in integrated pest management programs [34].

The practice of mixed farming where different crops are cultivated in the same piece of land is quite common in the type of farming system practiced in Sierra Leone, and in some instances can pose some challenges in the management decision of *B. tabaci* for such farming system. Significant number of smallholder farmers practice this kind of farming and their practice is mostly limited to traditional knowledge. To realize greater benefits of mixed farming, there is need to improve on the knowledge of mixed farming which can be achieved in the following ways: Capacity building of smallholder farmers through training on crop rotation strengthening their understanding the scientific principles of crop rotation. This helps farmers to optimize nutrient utilization and restoring and conserving greater values of soil biodiversity and essential values. Strengthening extension service providing requisite knowledge and technical guidance to farmers through demonstration farms can empower farmers to practically engage in designing plots for different crops to realized better outcomes. Sharing of resource materials and engagement of growers through teaching aids, seminars and workshops to adhere to principles and practical demonstration for enhanced productivity.

However, the knowledge of demographic parameters of *B. tabaci* on the test materials provides invaluable information on the strategy of management of the *B. tabaci*. Findings in this study indicated that tomato is the most suitable host whilst sweet pepper was the least preferred, where the fitness of *B. tabaci* was adversely influenced. The high rates of survival of smaller immatures observed in this investigation strongly suggest that management intervention is most preferred during the early stage of infestation. It is recommended that economic decision tools with respect to Economic Threshold (ET) and Economic Injury Level (EIL) of *B. tabaci* on these test materials will provide further information on timely intervention of management *B. tabaci* on these vegetable crops.

4. Conclusion

Mixed farming is commonly practiced in Sierra Leone where different crops are

cultivated on the same piece of land and are subjected to economic pests like *B. tabaci* showing generalist feeding behavior. In such a situation, the management of this category of pest will pose a serious challenge to timely and precise intervention targeting vulnerable and destructive stages. Knowledge gained from this study will provide invaluable information to farmers and policy makers on the timely application of control measures to manage *B. tabaci*. Furthermore, farmers would be advised to practice monoculture where they would concentrate on the cultivation of a single crop at a time where management of *B. tabaci* will be more effective and realistic as the vulnerable and destructive stages will be well identified and targeted on time, underscoring the importance of precision agriculture.

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Authors' Contribution

The authors significantly contributed to the realization of this research. No conflict of interest in field, laboratory and data analysis.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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