COMPARATIVE ANALYSIS OF DIFFERENT FRUITS TO DETERMINE THE FITNESS PARAMETERS OF *BACTROCERA DORSALIS* (DIPTERA: TEPHRITIDAE) USING AGE-STAGE, TWO SEX LIFE TABLE

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Abstract. The oriental fruit fly *Bactrocera dorsalis* is considered a destructive and invasive quarantine pest in various countries including "Pakistan". As invasive pest populations grow in new habitats, a better understanding of the occurrence dynamics of these pests will assist in formulating prevention and control strategies. It is important to have a good understanding of life tables to monitor a field dynamic and examine the population ecology. Fitness parameters of *B. dorsalis* on guava, mango and apple were evaluated using the "age-stage two sex" life table. Significant differences were recorded among each stage of *B. dorsalis* on different fruits. The incubation period of eggs on guava, mango and apple was 3.03, 3.56, and 3.53 days, respectively. The mean developmental period of 3rd instar larvae fed on guava, mango and apple was 3.58 ± 0.13, 3.75 ± 0.18 and 5.00 ± 0.14 days, respectively. The pupal duration was recorded lowest (7.58 ± 0.17 d) on guava as compared to other treatments i.e., mango (10.95 ± 0.17 d) and apple (11.62 ± 0.22 d). Adult longevity was higher (105.00 ± 0.63 d) on guava fed larvae than on other treatments. Moreover, a significant difference was recorded in fecundity on the tested hosts i.e., 1242.45 eggs on guava, 989.09 eggs on mango and 801.72 eggs on apple. The data showed that guava is the most suitable host on which the highest fitness parameters were recorded and the lowest on apple. Thus, the pulp of fully ripened guava fruit can be used in attractant baits to monitor and manage this economic pest.
Keywords: *Bactrocera dorsalis, quarantine pest, fruits, Pakistan*

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Introduction

Bactrocera dorsalis is a damaging pest of agricultural and horticultural crops around the globe, capable of causing damage to over 250 different kinds of vegetables and fruits, including guava, apple, peach, and mango. Female fruit flies penetrate the outermost layer of fruits with their ovipositor and deposit eggs inside the surface of fruits and vegetables. Maggots feed on the pulpy material, causing a release of watery fluid from the punctured fruit (Murtaza et al., 2021). Among the globally reported 128 fruit flies spp., 98 of these species are found in India and Pakistan. Of these, 48 species are known to attack mangoes and other economically important fruits. The per capita economic loss in Pakistan owing to fruit flies amounted to 144.6 million dollars (US), as reported by Stonehouse et al. (2002); Sarfraz et al. (2007); and Khan (2023).

These small creatures are the hurdle in exporting and importing several fruits, especially guava, mango, orange and apple, in various countries like Pakistan. The proper control measures are required to protect the agricultural and horticultural crops from this destructive pest. Understanding the seasonal variation of this economically important pest in various ecosystems and their capacity for population growth in novel surroundings is crucial for developing appropriate measures to prevent and manage the growth of their populations (Jaleel et al., 2018b). Life tables are vital for observing field dynamics and investigating population ecology (Bussaman et al., 2017; Huang et al., 2018). It is also essential for assessing the potential harm caused by invasive pests (Huang and Chi, 2012). This new method accurately represents the stage differentiation, survival, development, and reproduction in insects to solve the issues raised in female-specific life tables (Huang and Chi, 2012; Núñez-Campero et al., 2014). Currently, in the specific investigation of insect pests, the age-stage two-sex life table is frequently used (Jaleel et al., 2018b; Li et al., 2018). There was a lack of such studies in the agroecosystem of Pakistan, which was necessary to conduct and provide proper information to researchers worldwide.

To fulfill this gap, the current study used apple, mango and guava fruits to feed *B. dorsalis* under laboratory conditions. *B. dorsalis* has diverse hosts that significantly impact its development, survival, and fecundity (Carrasco et al., 2015). In this research, we analyzed the fitness parameters like developmental duration, life history traits and fecundity of *B. dorsalis* using an age-stage two-sex life table on three different fruits guava, mango and apple. The results perceived from the current study will be helpful in the comprehensive control and prevention of *B. dorsalis* in the globe especially in Punjab, Pakistan.

Materials and methods

Insects

Bactrocera dorsalis individuals were obtained from the research group at the Department of Entomology, University of Agriculture Faisalabad, Pakistan, and have been reared indoors for multiple generations. *B. dorsalis* was reared on the mango and guava under 25 ± 1°C, 65 ± 5% RH laboratory conditions. The adult diet contained water, yeast hydrolysate, and sugar.

Host plants

The Guava (*Psidium guajava*), Mango (*Mangifera indica*) and apple (*Malus pumila*) were used in this study, which were obtained from the local market in Faisalabad, Punjab,

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Pakistan. These fruits were fresh and free from any kind of diseases or pests. Furthermore, we thoroughly cleaned and immersed the fruit in sterilized water for 2 hours to avoid any potential presence of pesticide residue or any other contamination.

Life table study

Total of ninety eggs were collected from third-generation *B. dorsalis* for life trait study and thirty eggs was used in each treatment guava, mango, and apple. The eggs were collected using a 200 ml perforated cup with almost 500 holes with an insect needle. Each egg was carefully transferred into a Petri plate (60 mm diameter) using a camel hairbrush containing the corresponding host; this method was repeated in every replication. The eggs were left to hatch for 24 hours. Each treatment consisted of thirty replications and the single egg was considered a replicate. Petri plates were checked daily to record the data from egg to pupation. The newly emerged adults were transferred into adult-rearing cages for pairing and oviposition. The eggs were collected per the procedure mentioned above and under the microscope. The fertility of eggs was also observed. In a scenario where the emergence of male adults is more than females or if any female died during the experiment, we were to pick a female from the crossholdings population and put it into the experiment cage. Pupae from each host were weighed using an electronic balance.

Data analysis

The collected data on different stages of *B. dorsalis* was analyzed using the age-stage two-sex life table (Chi and Liu, 1985; Hsin Chi, 1988) and TWOSEX-MS Chart program (Chi, 2021). Using the age-stage two-sex life table, m_x, l_x and R_0 values were calculated. Here m represents the number of stages, and S_{xj} represents the probability that a newborn will survive and grow to age x and stage j. The number of offspring produced by a female at age x was represented by f_{xj}.

$$m_x = \frac{\sum_{j=1}^{m} S_{xj} f_{xj}}{\sum_{j=1}^{m} S_{xj}} \tag{Eq.1}$$

$$l_x = \sum_{j=1}^{m} S_{xj} \tag{Eq.2}$$

The net reproductive rate (R_0) is calculated as:

$$R_0 = \sum_{x=0}^{\infty} l_x m_x \tag{Eq.3}$$

The intrinsic rate of increase (r) was calculated following the methods of (Goodman, 1982):

$$\sum_{x=0}^{\infty} e^{-r\,(x+1)}\, l_x m_x = 1 \tag{Eq.4}$$

The finite rate of increase (λ) was calculated as:

$$\lambda = e^{r} \tag{Eq.5}$$

We calculated the mean generation time (T) as:

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$$T = \frac{ln\, R_0}{r} \quad \text{(Eq.6)}$$

The age-stage life expectancy (e_{xj}) was calculated according to the formula described by Chi and Su (2006). Where x represents an individual's age and j represents an individual's stage.

$$e_{xj} = \sum_{i=x}^{\infty} \sum_{y=j}^{m} S'_{iy} \quad \text{(Eq.7)}$$

where s'_{iy} can be calculated by considering $s'_{iy} = 1$ (Tuan et al., 2014). Utilizing (Tuan et al., 2014) methodology, the v_{xj} was calculated as:

$$V_{xj} = \frac{e^{r(x+1)}}{S_{xj}} \sum_{i=x}^{\infty} e^{-r\,(i+1)} \sum_{y=j}^{m} S'_{iy} f_{iy} \quad \text{(Eq.8)}$$

Age-stage specific survival rate (S_{xj}): where x is age and j is the stage

$$S_{xj} = \frac{n_{xj}}{n_{01}} \quad \text{(Eq.9)}$$

The bootstrap procedure with 100,000 resampling's was used to estimate the standard errors of various life table parameters, such as egg incubation period, larval development and pupation duration, eclosion rate, pupal weight, survival rate, male and female longevity, oviposition duration, fecundity and TPOP—a paired bootstrap test used to compare the differences between treatments (Wei et al., 2020).

Results

The mean developmental duration of each stage is summarized in *Table 1*. The noteworthy differences were recorded among each stage of *B. dorsalis* on different fruits. The incubation period of eggs on guava, mango and apple was 3.03, 3.56, and 3.53 days, respectively. The developmental periods of 1st, 2nd and 3rd instar larvae of *B. dorsalis* fed on guava significantly differed from other tested hosts. The developmental period of 3rd instar larvae fed on guava, mango and apple was 3.58, 3.75, and 5 days, respectively (*Table 1*). The pupal duration of guava was 7.58 ± 0.17 compared to mango 10.95 ± 0.17 days and apple 11.62 ± 0.22, respectively. Adult longevity was higher in guava fed adults at 105.00 ± 0.63 compared to mango and apple. The longevity was 103.27 ± 0.54 and 96.00 ± 0.65 days, respectively (*Table 1*).

Results indicated that there was a remarkable difference were recorded in the reproduction, adult pre-oviposition period (APOP), total pre-oviposition period (TPOP) and oviposition period on guava (5.00 ± 0.00, 27.90 ± 0.40, 75.00 ± 0.74 days), mango (7.00 ± 0.00, 30.90 ± 0.40, 71.18 ± 0.67 days) and apple (8.00 ± 0.00, 34.45 ± 0.53, 60.45 ± 0.46 days) respectively. The highest fecundity was recorded on guava (1242.45 ± 21.03), followed by peaches (989.09 ± 15.10) and apples (801.72 ± 19.88) (*Table 1*).

The significant differences in fitness parameters of pests were observed as shown in *Table 2*. The highest R_0 (455.56) was recorded on guava, followed by mango (362.66) and apple (293.96). The highest *r* was observed on guava and the lowest on apple. The

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T value on guava, mango and apple was 36.78, 41.56 and 43.95 days, respectively (P < 0.0001) as given in *Table 2*.

Table 1. *The developmental periods, male and female longevity, fecundity, TPOP, oviposition period, and fecundity of Bactrocera dorsalis on three host fruits, along with their means and standard errors*

Parameters	Guava	Mango	Apple
	Mean ± SE	Mean ± SE	Mean ± SE
Egg	3.03 ± 0.11 c	3.56 ± 0.16 a	4.53 ± 0.18 a
1st instar	2.63 ± 0.11 c	2.96 ± 0.17 a	2.7 ± 0.14 a
2nd instar	3.00 ± 0.11 c	3.12 ± 0.12 a	3.41 ± 0.10 a
3rd instar	3.58 ± 0.13 c	3.75 ± 0.18 b	5.00 ± 0.14 a
Pupa	8.58 ± 0.17 c	10.95 ± 0.17 b	11.62 ± 0.22 a
Male longevity (Days)	91.61 ± 0.63 a	82.76 ± 1.00 b	81.38 ± 0.83 c
Female longevity (Days)	105. ± 0.63 a	103.27 ± 0.54 b	96.00 ± 0.65 c
APOP (d)	5.00 ± 0.00 c	7.00 ± 0.00 b	8.00 ± 0.00 a
TPOP (d)	27.90 ± 0.40 c	30.90 ± 0.40 b	34.45 ± 0.53 a
Oviposition (Days)	75.00 ± 0.74 a	71.18 ± 0.67 b	60.45 ± 0.46 c
Fecundity	1242.45 ± 21.03 a	989.09 ± 15.10 b	801.72 ± 19.88 c

a, b and represent the significant differences among different treatments. (p > 0.05). The d represents the days

Table 2. *Population parameter of B. dorsalis on different fruits*

Parameters	Guava	Mango	Apple
	Mean ± SE	Mean ± SE	Mean ± SE
r	0.16 ± 8.14 a	0.14 ± 7.24 b	0.12 ± 6.74 c
λ	1.18 ± 9.58 a	1.15 ± 8.32 b	1.13 ± 7.64 c
GRR	586.6 ± 125.24 a	493.14 ± 95.57 a	395.95 ± 79.62 c
R0	455.56 ± 109.80 a	362.66 ± 87.25 a	293.96 ± 71.06 b
T	36.78 ± 0.49 c	41.56 ± 0.54 b	43.95 ± 0.69 a

r: Intrinsic rate of increase (P > 0.05), λ: Finite rate of increase, *GRR*: Gross reproductive rate (offspring), R_0: Net reproductive rate (offspring/individual), *T*: Mean generation times

Curves in *Figure 1* illustrate the chance of survival from egg to age x and stage j, and the age-stage specific survival rates (S_{xj}) are displayed on the three host fruits (*Figure 1*). Statistical analysis shows that the eclosion time of both males and females on guava was earliest compared to mango and apple (19, 20 and 23 days), respectively, while in females (18,20 and 22) as shown in *Figure 1*. The developmental duration and growth create a curve that overlaps at different instar stages. The impact of tested host fruits on the life e_{xj} of *B. dorsalis* is shown in *Figure 2*. e_{xj} of *B. dorsalis* on guava was highest compared to other tested fruits (*Figure 2*).

The population growth of the pest was assessed through v_{xj} value which refers to how individual pests contribute to the forthcoming population development at age x and stage j. The reproductive value of this pest on guava, mango and apple was 305, 247 and 244, respectively shown in *Figure 3* which was the maximum in guava.

Age-specific fecundity (mx), age-specific survival rate (l_x), age-stage specific fecundity (f_{x4}) and age-specific maternity (l_x*m_x) of B. dorsalis on tested fruits are shown in *Figure 4*. The results show that the f_{x4} values appeared on the 30th day on guava, 38 days

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on mango, and 40 days on apple. m_x values on guava, mango and apple were recorded at 30, 33 and 39 days, respectively, while l_x*m_x values were 31, 34, and 39 days (*Figure 4*).

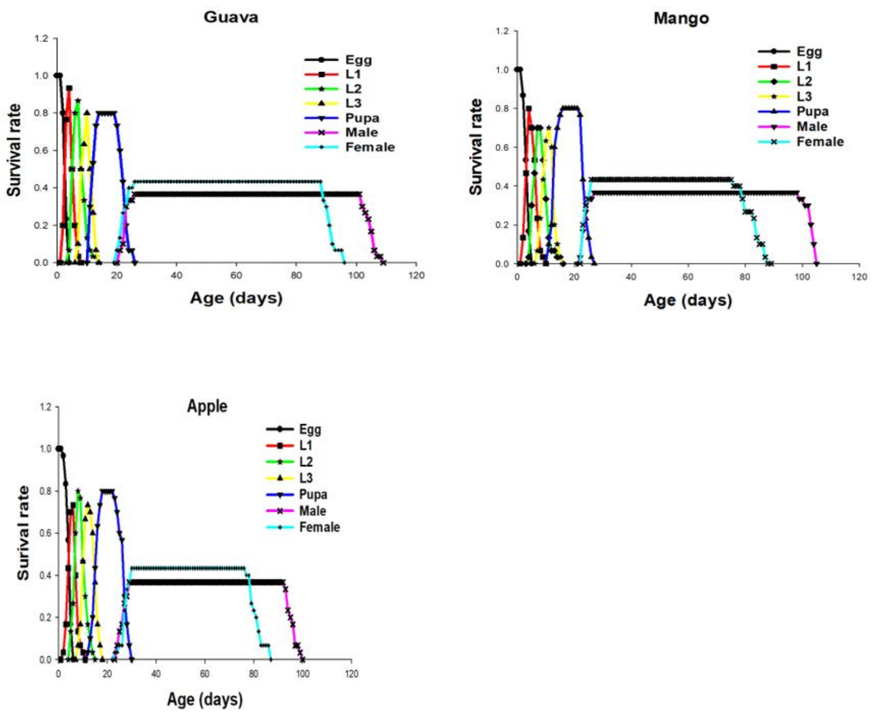

Figure 1. *The age-stage specific survival rates (S_{xj}) of Bactrocera dorsalis on different host fruits. L1, L2, and L3 represent 1st, 2nd and 3rd instar larvae, respectively. The data obtained was compared using the paired bootstrap test (P< 0. 05)*

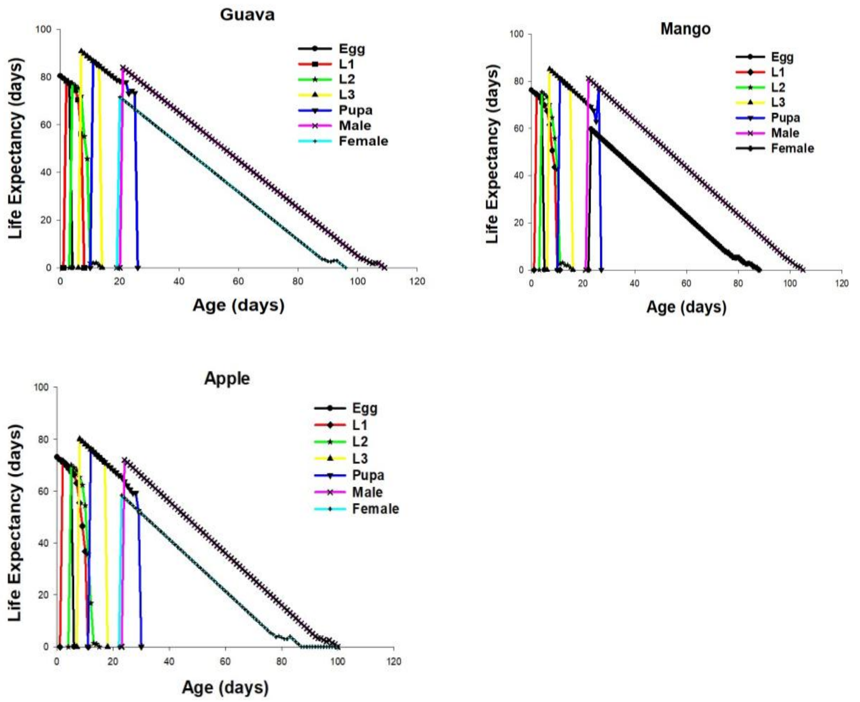

Figure 2. *The impact of tested fruits e_{xj} of B. dorsalis. The data obtained was compared using the paired bootstrap test (P< 0. 05)*

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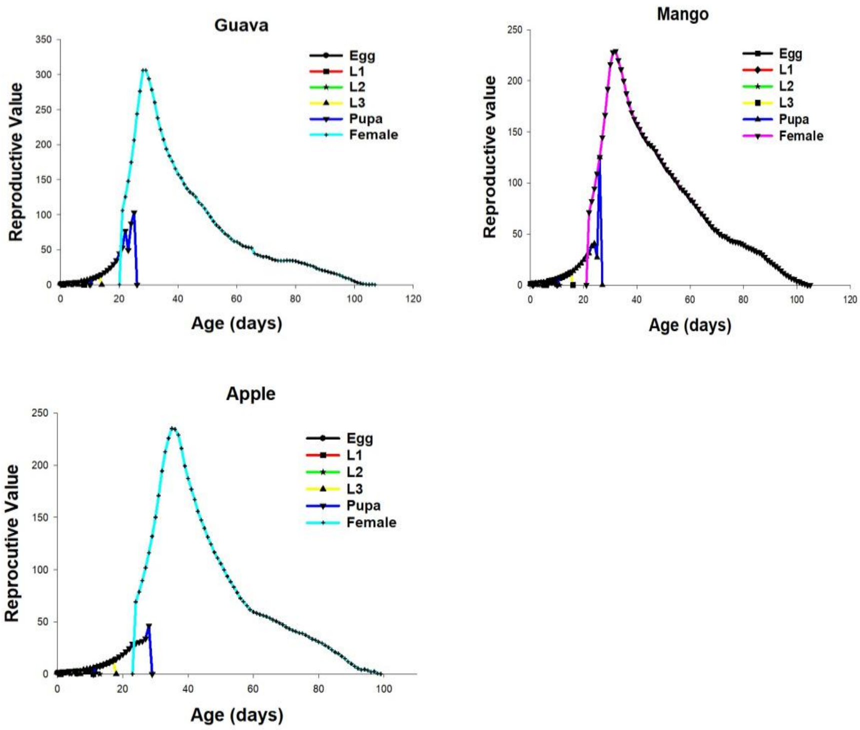

Figure 3. *Hosts effects on the reproductive value (v_{xj}) of B. dorsalis. L1, L2, and L3 represent 1st, 2nd and 3rd instar larvae, respectively. The data obtained was compared using the paired bootstrap test (P< 0. 05)*

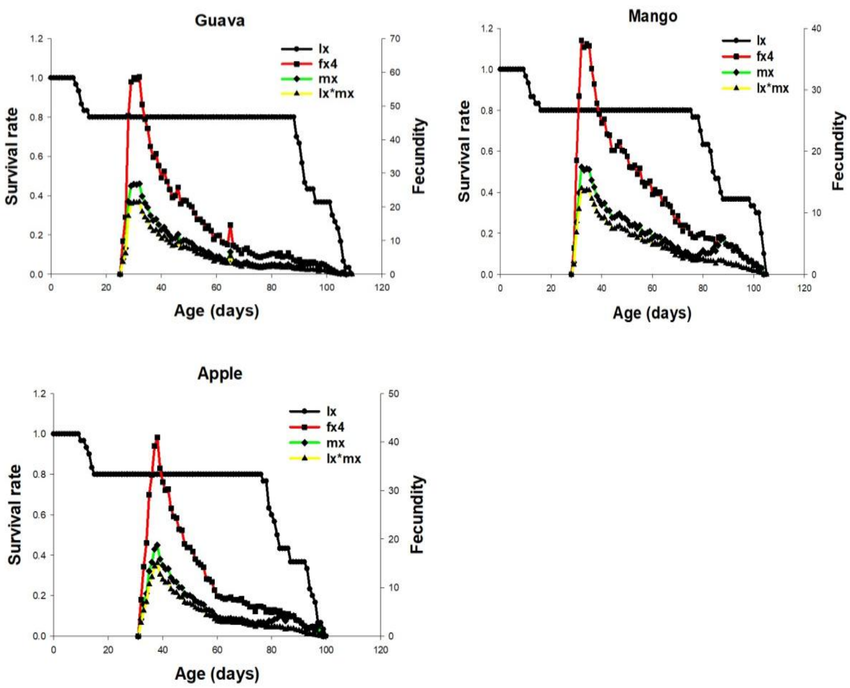

Figure 4. *l_x, f_{xj}, m_x and l_xm_x of B. dorsalis on the tested host fruits. The data obtained was compared using the paired bootstrap test (P< 0. 05)*

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We observed that maximum pupal weight was recorded in guava fed larvae (17.02 mg) compared to mango and apple (15.13 and 13.98 mg) as shown in *Figure 5*.

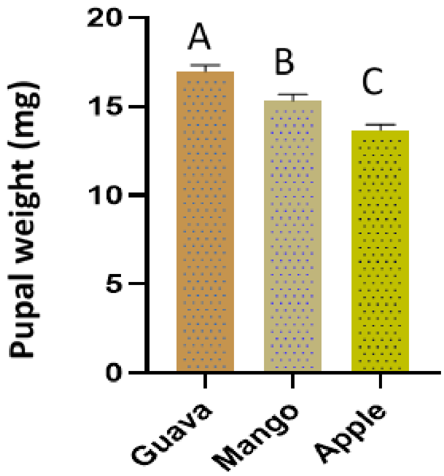

Figure 5. *Pupal weight of fruit fly on different tested fruits*

Discussion

Oriental fruit fly *Bactrocera dorsalis* (Hendel) is considered a most destructive and invasive quarantine pest in various regions and countries including Pakistan. Usually, the researcher observed that if the host plant is most susceptible and favorable for the development of an insect, then the development is short, fecundity is maximum and a higher survival rate (Söderlind, 2012). As invasive pest populations grow in new habitats, a better understanding of the occurrence dynamics of these pests will assist in formulating prevention and control strategies. It is important to have a good understanding of life tables to monitor a field's dynamics and examine the population's ecology. However, the present study analyzed the fitness parameter of *B. dorsalis* using the age-stage two sex life table on guava, mango and apple.

Fruits with soft skin have been reported as the most susceptible for *Bactrocera* spp. (Fitzpatrick, 2009; Jaleel et al., 2018a). Our results demonstrated that guava fruit is more suitable for oviposition because the skin of guava fruit is softer and thinner compared to the other tasted fruits (*Table 1*). The development and reproduction rate of insects is maximum on their favorable hosts (Musa and Ren, 2005; Murtaza et al., 2021). We found that this pest's development and reproduction rate was maximum on guava compared to other host fruits; our results are the same in line with (Jaleel et al., 2018b). When examining the fitness and population of insect pests, such as *Bactrocera* fruit flies, the developmental stage and body weight are crucial variables to consider Waseem et al. (2012). The developmental time of larvae and pupae of *B. dorsalis* are different among different host fruits. Several fruits, including mango, pear, peach, chili, and cucumber, have been found to have a larval and pupal period of 8–11 days and 8-9 days, respectively (JIANG 2001). While Jaleel et al. (2018b) reported that the larval and pupal duration was 2-4-and 5-6 days, we recorded that the larval and pupal duration were 9-11 and 8-11 days, respectively. *B. dorsalis* larvae complete their larval and pupal stage earlier on the guava fruits than mango and apple (*Table 1*). The results revealed that the female and male longevity on guava was 91 and 105 days while on mango and apple was (82 and 103 days,

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81 and 96 days) respectively, while Jaleel et al. (2018b) investigated that the male and female longevity was 108 and 125 days.

Insect fecundity is the most important aspect of the insect population dynamic (Jaleel et al., 2019). The fecundity of *B. dorsalis* is positively correlated with the host fruit (Waseem et al., 2012). In the present study maximum fecundity was recorded on guava (1242 eggs) fed larvae as compared to Mango and apple-fed larvae (989 and 801 eggs) (*Figure 4*) that are in favor of Vargas et al. (1997) and Jaleel et al. (2018a).

A key parameter for predicting maturity, sex ratio, survival, and fecundity of insect pests is r, an important parameter for growth, development, and survival (Chen et al., 2017). The results of our study (*Table 2*) are consistent with demographic theory, which states that a host is suited for population increase if r is greater than zero (0) (Chen et al., 2017; Jaleel et al., 2018a). According to Musa and Ren (2005), higher intrinsic rise rates also indicate a host's vulnerability to insect attack (Sayyed et al., 2008) stating that R_0 is a crucial measure of population development, with the number of eggs determining the maximum population rate. The study found that rearing flies on guava resulted in the highest net and gross reproductive rates (*Table 2*). The result showed that the GRR value is higher in guava fed population than in other tested host fruits (*Table 2*). The GRR is a sign of a sharp rise in insect population dependent on fecundity and adult eclosion (Huang and Chi, 2012; Chen et al., 2017).

Based on our findings, we summarized that the larval, pupal development, adult longevity and female fecundity were maximum recorded on guava fruit. So, the pulp of fully ripened guava fruit can be used in the attractant baits to monitor and manage this economic pest. The current findings will be helpful for future researchers to conclude which host is suitable for developing bait or attractants in pest management.

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Conflict of interest. Authors declare there is no conflict of interest.

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